Canadian Institute of
Guided Ground Transport
Queen's University
at Kingston, Ontario

A. van Eyken
S. Perlin

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CONCEPTUAL DESIGN OF SNOW REMOVAL EQUIPMENT FOR MAIN TRACKS

prepared by

A. van Eyken
S. Perlin

for

Transportation Development Centre, Transport Canada

Canadian Institute of Guided Ground Transport
Queen's University at Kingston, Ontario
K7L 3N6

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PROJECT TEAM

A. van Eyken, Research Fellow, CIGGT
S. Perlin, Design Engineer

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17. Abstract

An advanced concept in snow clearing equipment, named SNOWMASTER, has been developed for use on railway mainline trackage. Designed to clear moderate snow cover by means of its plowing surfaces, the SNOWMASTER can also clear drifts up to 15 feet (4.57 m) deep, such as may occur in cuttings, by deploying its on-board snowblower system. The latter is fixed to articulated deploying booms which can place the snowblower in position ahead of the plowing surfaces. When not in use, the snowblower is parked in a cavity behind the operator's cab. A unique feature of the design is the variable geometry plowing surface which allows snow to be cleared to the right, to the left, or half each side, the choice depending on the track configuration, physical obstructions and the nature of the terrain. Retractable wings and rail flangers are included. SNOWMASTER features a turntable which allows the unit to be reversed without losing rail contact, thus permitting bi-directional operation. Although the unit would normally be used as part of a locomotive-powered consist, it is capable of propelling itself at speeds of up to 5 mph (8 km/h) through a hydrostatic transmission. SNOWMASTER is powered by two diesel engines: one 650 hp unit provides snowblowing power; the other 150 hp unit is for main propulsion. These units also provide power for the auxiliary hydraulic systems, electric generator and air compressor. Accommodation for five crew members is provided, including dining, kitchen, closet and washroom facilities.

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17. Résumé

Ce rapport décrit le chasse-neige de type avancé appelé SNOWMASTER mis au point pour usage ferroviaire. Il est conçu pour déblayer des surfaces enneigées à des profondeurs moyennes à l'aide d'éléments chasse-neige, mais il est également capable de dégager des congères atteignant 4,57 mètres de hauteur, dans les tranchées, par exemple, en mettant en oeuvre la souffleuse embarquée. Ce dispositif est monté sur bras articulés qui le positionnent devant les éléments chasse-neige lorsque le besoin s'en fait sentir; escamoté, il est rangé dans un espace derrière la cabine de commande. Caractéristique unique, ce chasse-neige à géométrie variable permet de déneiger à droite, à gauche ou à gauche et à droite, selon le tracé de la voie, les obstacles et la nature au sol. Des ailerons élargisseurs et un soc d'entre-rails sont inclus. Le SNOWMASTER comporte une table tournante qui permet à l'engin de pivoter sur lui-même et de poursuivre son travail dans l'autre sens. En mode normal, l'engin est poussé par une locomotive, mais il peut aussi se déplacer tout seul à une vitesse maximum de 8 km/h grâce à une transmission hydrostatique. Le SNOWMASTER est équipé de deux moteurs diesel: une de 650 hp qui actionne la souffleuse et l'autre de 150 hp pour la traction. Ces moteurs entraînent également les pompes des systèmes hydrauliques, le groupe électrongène et le compresseur d'air. Les cinq personnes qui ont place à bord disposent d'un espace pour cuisiner et manger ainsi que d'installations sanitaires.

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EXECUTIVE SUMMARY

A new concept in mainline snow clearing equipment called SNOWMASTER has been developed for potential use on mainline railway track. It is the second phase of a two-phase development program to update snow clearing equipment for Canadian railway operations, the first phase dealing with yard clearing being already completed under the code name "SNOWFIGHTER".[1]

The SNOWMASTER is a vehicle equipped with systems which are intended specifically for use on Canadian mainline railway track. These systems are designed to handle snow clearing requirements in the winter conditions normal to the Canadian experience.

Basically, the SNOWMASTER is a snowplow which operates with a locomotive. It has unique variable geometry snowplowing surfaces. These may be deployed hydraulically to remove moderate snow cover from the track either all to the right, all to the left, or half each side. A rectractable flanger is provided on the elevation wedge of the plowing surfaces.

In terrain which is prone to deep drifting conditions such as may be experienced in cuttings, the SNOWMASTER is able to remove snow up to 15 feet (4.57 metres) deep by deploying its snowblowing equipment. The latter consists of a two-stage snowblower which is normally parked in a slot located near the centre of the vehicle. The blower is deployed by means of two hydraulically operated, articulated booms which place it ahead of the snowplowing surfaces. These booms can be programmed to move the blower up and down and so dispose of deep snow drifts otherwise impassable to snowplows.

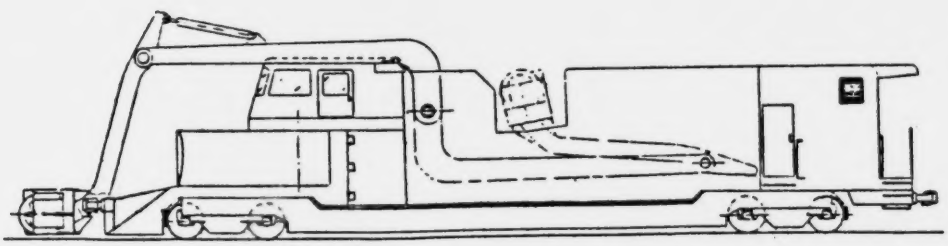
The snowblower has the capacity to remove 3,000 tons per hour. It consists of a primary stage auger which feeds twin snowblowers. The latter are able to discharge snow to either side or half each side and are capable of casting the snow to a distance of 75 feet (22.9 metres). Because of the inching progress required during snowblowing operations, the vehicle is self-propelled by means of a separate power unit employing a hydrostatic transmission. This system is also capable of propelling the vehicle at 5 mph (8 km/h) for "hostling" purposes.

The upper part of the SNOWMASTER, including the control cab, the plowing surfaces and the blower, is supported on a turntable which is in turn supported on the underframe of the vehicle. This enables the system to be reversed without losing wheel/rail contact, thus making the vehicle bi-directional.

SNOWMASTER is fitted with a driver's cab equipped with central control systems for variable geometry plow surfaces, blower, turntable and propulsion systems. There is also a facility for remote control of a locomotive. In addition, there are on-board cooking, toilet and locker storage facilities.

Power for the vehicle is provided by two engines: one for driving the blower system and the other for the propulsion and auxiliary systems.

The accompanying illustration gives a general impression of SNOW-MASTER. The overall length is 69 feet (21 metres) and approximate weight is 70 tons.



SNOWMASTER

RÉSUMÉ

Un chasse-neige de type avancé appelé SNOWMASTER a été étudié et mis au point pour usage ferroviaire, dans le cadre d'un programme en deux phases visant à moderniser les opérations de déneigement des grandes lignes de chemin de fer au Canada. La première phase du programme s'était intéressée au déneigement des gares de triage et avait reçu le nom de SNOWFIGHTER.

Le SNOWMASTER est un engin conçu expressément pour les besoins des chemins de fer canadiens, les systèmes qu'il comporte étant étudiés en fonction des conditions climatiques particulières au Canada.

Prévu pour être poussé par une locomotive, le SNOWMASTER se caractérise par la géométrie variable de ses éléments chasse-neige qui, mus hydrauliquement, peuvent déblayer des profondeurs moyennes d'enneigement, à droite, à gauche ou à gauche et à droite de la voie. Un soc d'entre-rails escamotable est placé sur l'étrave de l'engin.

Celui-ci est capable de dégager des congères atteignant jusqu'à 4,6 mètres de profondeur, dans les tranchées, par example, un mettant en oeuvre la souffleuse embarquée, qui comporte une fraise de deux turbines et s'escamote dans une fente aménagée dans l'axe longitudinal de l'engin. La souffleuse est montée sur deux bras hydrauliques articulés qui la positionnent devant les éléments chasse-neige. Ces bras sont programmables de manière à donner à la souffleuse un mouvement alternatif dans le plan vertical, seul moyen pour éliminer les congères de grande hauteur infranchissables autrement.

D'une capacité de 3 000 tonnes par heure, l'engin comporte une fraise alimentant deux turbines qui peuvent décharger à une vingtaine de mètres sur un seul côté ou sur deux côtés à la fois. L'engin est capable de se mouvoir de manière autonome, grâce à un moteur et à une transmission hydrostatique qui lui permettent d'avancer très lentement lorsque le déneigement se fait, ou bien à un maximum de 8 km/h lorsqu'il fonctionne "haut le pied".

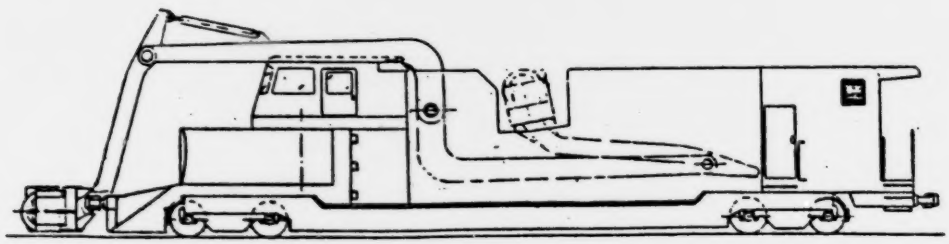
Toute la superstructure de l'engin, y compris la cabine de commande, les éléments chasse-neige et la souffleuse, est montée sur une table

tournante reposant sur le châssis même de l'engin, de sorte que celui-ci peut pivoter sur lui-même et poursuivre dans le sens opposé sans perte d'adhérence.

Dans la cabine se trouvent les commandes nécessaires pour actionner les éléments chasse-neige, la souffleuse, la table tournante et les moteurs et, aussi, pour télécommander une locomotive. A bord ont été prévus des espaces cuisine, rangement et sanitaires.

Le SNOWMASTER est équipé de deux moteurs diesel : un pour actionner le souffleuse et l'autre pour la traction et les systèmes auxiliaires.

Le dessin ci-dessous illustre le SNOWMASTER qui a 20 mètres de longueur hors tout et pèse 70 tonnes, environ.



SNOWMASTER

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1. INTRODUCTION

The problem of snow removal is a major concern for all railway systems which must operate in areas of heavy snowfall. However, Canadian railway snow removal technology has remained quite static over the past three decades.

The results of a study conducted during the winter of 1978/79 on snow removal equipment in present use in the Japanese National State Railways, Swedish State Railways and Norwegian State Railways, was reported in September 1979.[2] It indicates that, "although each country had several pieces of equipment of interest, no particular machine was judged to have all the desirable features necessary for Canadian railway operations." It was accordingly recommended that the development of appropriate modern technology be split into two phases -- Phase I being for yard and terminal areas, and Phase II for main tracks.

Phase I, which resulted in the development of "SNOWFIGHTER,"[1] is already complete. It culminated in the assembly and testing of a highly successful piece of equipment used for yard and terminal clearing.

Phase II, the development of "Railway Snow Removal Equipment for Main Track," is the subject of this report.

This phase, funded by the Transportation Development Centre through CIGGT, has developed a conceptual design for a snow clearing system called "SNOWMASTER."

2. FUNCTIONAL PERFORMANCE REQUIREMENTS

Following discussion with the Transportation Development Centre and Canadian National Railways, the functional requirements for the conceptual design of the SNOWMASTER were drawn up. These are as follows:

1.0 **Introduction**

1.1 The design of the snow removal vehicle to be such that it will provide high-efficiency, up-to-date snow clearing service for mainline track.

2.0 **General arrangement**

2.1 The vehicle to include the following snow removal equipment:

- wedge-type snowplow
- two-stage snowblower
- side wings
- flange equipment

2.2 The wedge-type snowplow to be capable of discharging snow all left, all right, or half each way. A rapid and positive method of changing the plow discharge direction to be used.

2.3 The two-stage snowblower to have the ability to discharge at 60° from the horizontal, either left or right, to a maximum throw distance of 75 feet (22.86 m).

2.4 The side wings to be capable of extending at an effective working angle to 8 feet (2.44 m) from the centreline of the vehicle. The wings to adjust in and out as well as up and down.

3.0 **Performance requirements**

3.1 The vehicle to be capable of travelling at 60 mph (96.6 km/h) when plowing and 65 mph (105 km/h) in transit. It is to be self-propelled to 5 mph (8 km/h) for hostling purposes.

3.2 The vehicle to be able to handle snow drifts of up to 15 feet (4.57 m). The maximum depth of snow to be plowed is 3 feet (0.91 m); reference snow depth versus speed curve to be supplied by TDC.

3.3 The operating temperature range is to be -50°F (-45.6°C) to 40°F (+4.5°C).

3.4 The snowblower to have a capacity of 3,000 tons/hour (2,722 tonnes/hour).

3.5 The vehicle to be self-turning (without losing wheel/rail contact) in order to provide bi-directional capability.

4.0 Physical arrangement

4.1 The vehicle, with side wings retracted, is to conform to the mechanical clearances specified in CN Spec. H.D. 37, Sheet 6-1 (ref. Figure 1). The vehicle to conform to the operating envelope specified in CN Standard Clearance Diagram RIU.1.1 (March 1941) (ref. Figure 2).

4.2 The vehicle to be able to negotiate a 850 foot (259 m) radius vertical curve and a 185 foot (56.3 m) radius horizontal curve.

4.3 The axle loadings are not to exceed 55,000 lbs (24,948 kg). The truck centres to be not less than 30 feet (9.14 m). The vehicle centre of gravity is not to exceed a height of 72 inches (1.83 m) above the top of the rail.

4.4 The vehicle to be equipped with a coupler and draft gear at each end for simultaneous coupling while being transported in an intermediate position in the train. The coupler centre line to be 34½ inches (0.88 m) above the top of the rail. Also, the coupler and draft gear to have a capacity of 400,000 lbf (1,779.9 kN).

4.5 The flanging equipment to be mounted immediately behind the rear truck and/or immediately ahead of the front truck.

4.6 The wings to be equipped with positive locking devices in the retracted position. Also, the wing assembly to incorporate safety shear pins.

4.7 The vehicle to be able to remotely control the locomotives.

4.8 The unit to be equipped with a locomotive-type cab containing all the engineman's controls, as well as all other operating controls. The cab to provide a 210° field of vision. The cab to have seating for an engineman, snowplow foreman, two maintenance-of-way employees, and a conductor.

4.9 The vehicle to contain a washroom and basic cooking facilities to eliminate the need for a caboose (van) and/or bunk cars.

4.10 An "on-board" diesel power pack to provide power for the blower, nose and wing positioning mechanisms, turning, propulsion, heating and lighting.

4.11 The maximum size permissible between truck centres and outside track centres to fall within the restrictions illustrated in the equipment resriction diagram (Figure 3).

4.12 The vehicle design to be such that good access to the truck/track area will be provided.

4.13 Safety equipment, grab irons, and steps on the vehicle to be identical to equipment furnished on CN-built cabooses.

3. OVERALL DESIGN CONCEPT

The embodiment of all the various mechanical features, and achievement of the performance criteria within the limits of the various restrictions laid out in the functional performance requirements, posed many problems in the development of a well integrated, functionally efficient, mechanically sound and aestheticaly pleasing design.

It was the intention initially to add one extra piece of equipment, namely a switch broom, to the SNOWMASTER system. It was found early in the program, however, that the inclusion of such a device in any practical design was virtually impossible. Hence, the requirement for a switch broom of conventional design was removed from the approved functional performance requirements.

Progress toward the finally accepted design resulted in a number of different configurations which were engineered to a degree permitting the production of a number of schematic drawings. It was felt that while a number of these designs were in fact rejected in the process, they should be included in this report since certain of the features appearing in them may be of value in the context of other snow clearing equipment for different duties. Accordingly, brief commentary on these preliminary designs is given in Appendix D.

The finally accepted overall design is shown in Drawings No. 1, Rev. 0 and 2, Rev. 0. This consists of a two-truck, flatbed underfame (17) which supports a turntable on which is mounted the main body (13) of

the SNOWMASTER. The latter includes the variable geometry plow system ((5), (7)) and the blower system ((1), (2), (3), (6), (12)), the engine room, crew accommodation and control cabin. The various components of the system are dealt with in the following text.

4. UNDERFRAME AND TRUCKS
Drawing No. 1, Rev. 0

The underframe (17) is essentially a flat bed supported on two two-axle trucks and fitted with a turntable at the centre. One axle of one of the trucks is capable of being driven for hostling purposes but all other axles are free.

Normally the SNOWMASTER will be propelled by a locomotive. However, for hostling purposes the vehicle is self-propelled up to 5 mph. An arrangement of the propulsion truck is shown on Drawing No. 3, Section F-F (the other truck is the same with the absence of traction motor and traction gearbox). Wheel diameter is 33 inches.

The transmission consists of an axle-mounted traction gearbox of approximate drive ratio 14.45:1 (see Section GG) to which is mounted a Sundstrand Series 27 fixed capacity hydrostatic motor (34). The operating pressure for the motor will be approximately 2,500 psi.

Since it would be undesirable to motor the hydrostatic transmission while the vehicle is being propelled by an attendent locomotive, the transmission is fitted with an axle-mounted Eaton Airflex 11.5VC 500 pneumatically operated clutch. The latter will be capable of decoupling the complete transmission system from the axle.

A conventional air brake system is provided with the truck assembly. This will be compatible with brake systems presently used on Canadian railways.

It is important to note that self-propulsion could be provided by an alternative electrical transmission system. However, the hydrostatic transmission was favoured because of the simplicity of the control and the characteristic properties which provide for infinitely variable transmission ratio and the availability of full torque at the traction wheels while moving forward at almost zero speed.

The latter feature would be particularly desirable in a deep drift snow-blowing operation where very low forward speed at full tractive effort may be required.

The propulsion system is described in greater detail in Section 8.

5. VARIABLE GEOMETRY PLOW

The versatile performance demanded by the plowing surfaces led to the concept of a variable-geometry plowing system. Rail vehicles are subject to certain outline restrictions for travelling in a train and certain clearance restrictions while plowing, to avoid damage to various trackside equipment such as signals, switch stands, poles, signs, etc. The demand for variable geometry and these clearance restrictions limit the choice of possible plow surface contours. In consequence, the optimum surface contour must be sacrificed in favour of the greater flexibility afforded by the variable geometry. The resulting plowing surfaces are therefore simplified in contour and consist basically of a fixed elevation wedge and a rotatable horizontal deflector wedge at the front end of the vehicle.

The fixed elevation wedge has a retractable, hydraulically operated flanger at the leading edge. The wedge is inclined at an angle of 35° to the rail and leads up to a horizontal platform approximately 4½ feet above the rail (ATR). The horizontal rotatable deflector wedge is located on this platform and is shown as item (7) on Drawing No. 1, Rev. 0, and in greater detail on Drawing No. 4, Rev. 0. As shown on the latter, the deflector wedge is a robust, hollow steel weldment, (7), the snow deflecting surfaces being strengthened from inside by a lattice of welded gussets.

The deflector wedge is pivoted on a very sturdy, hollow steel column located ideally at the centre of pressure of the deflecting surfaces. (Because of the variable geometry, the latter may only be true for one position of the wedge.) This will minimize the effort required to rotate the wedge when plowing snow.

Deployment of the wedge is by means of twin, double-acting, push/pull hydraulic actuators (39) located inside the casing. The latter are anchored to a post (Wedge Buffer Stop, (30)) projecting up from the

elevation wedge platform. The latter acts both as anchor for the actuators and as a stop for the wedge when deployed either to the right or the left. In addition, a hydraulically-operated wedge locking cylinder (35) is located in the nose of the wedge. This registers in holes in the platform at each of the three positions of the wedge. All of the wedge operating mechanism, including the wedge stops and locking cylinder, are located inside the wedge casing. They are thus shielded from the elements and therefore not subject to fouling from the snow.

Access to the wedge-operating hydraulic actuators, etc., for maintenance purposes is provided through a door in the casing at the rear of the wedge. This is accessible from inside the body of the SNOW-MASTER when the wedge is in the central position.

6. SNOWPLOW WINGS

The plowing width of the snowplow is extended to 16 feet by the side wings (item (18)) which are located behind the driver's cab (see Drawings No. 1 and 2). They are deployed by means of pneumatic cylinders and, as shown, the wings consist of two sections each, the upper section being hinged to the rotatable main body of the vehicle and the lower section being hinged to the underframe. Since the latter does not rotate, the lower section of the sidewings is duplicated at the other end of the underframe for plowing in the reverse direction.

It was considered that the lower sections of the wings could be retracted when necessary to clear track-side equipment, and that the clearance thus provided would be sufficient for all purposes. However, it was subsequently discovered that wings that could be moved vertically would provide greater flexibility in snow-clearing operations. With some modifications to the wing mechanism and pneumatic deploying actuators, it would be quite possible to provide this feature.

Provision of pneumatic rather than hydraulic actuators for the wings was made because of the low inertia and compressibility of air. The wings will be deployed with the actuators held at constant pressure, the control valves being held open. In this condition, the actuators would be connected to the air reservoir via a pneumatic pressure-reducing valve fitted with a reduced pressure side relief valve. If the

wings accidentally come against a track-side obstruction, they will be forced to retract without damage to the systems, while venting air through the relief valve. As a back-up safety measure, the deploying actuators may be fitted with shear pins which will give way at a certain predetermined load.

7. SNOWBLOWER SYSTEM AND DEPLOYMENT MECHANISM

The snowblower system consists of a primary and secondary system (see Drawings No. 5, 6, 7 and 8). The primary system consists of a snow auger revolving at 400 rpm. This auger feeds the snow into two snowblowers revolving at 450 rpm. The latter are able to cast the snow over a distance of 75 feet to either side of the track. Capacity of the snowblower system is 3,000 tons per hour, approximately, with a clearing width of 11 feet.

The mechanism of the snowblower system is driven hydrostatically. In the case of the auger, the transmission is shown on Drawing No. 8. An Abex No. 11 fixed-capacity hydrostatic motor bolted to the framework drives the auger via a splined shaft, bevel pinion and crown wheel right-angle drive located at the centre of the auger. Separate Abex No. 11 hydrostatic motors drive each of the two blowers via separate chain drives (see Drawings No. 5, 6, 7 and 8). The trajectory of the cast snow is directed by the movable casings of the blowers. These are oriented by rotating the casings by means of small rotary abutment-type hydrostatic motors which rotate the casings by means of a chain wheel which meshes with a steel roller chain wrapped around the outer periphery of the circular blower casing (see Drawing No. 5).

When it is deployed, the snowblower is positioned ahead of the plowing surfaces (see Drawing Nos. 1 and 2) by means of the deploying arms (6) and (12). The latter may be controlled to oscillate the blower system vertically so as to facilitate the clearing of deep drifts. The hydraulic fluid conductors leading to the hydrostatic drive motors on the blower will be routed through the hollow section of the deploying arms.

When not in use, the blower will be parked in a slot mid-way along the body of the vehicle. In this position, the blower arms are folded

behind the driver's cab as shown in Drawing No. 1, in such a way so as not to obstruct the rearward side vision of the driver.

Operation of the blower deployment arms is by means of hydraulic elbow cylinder actuators (see item (9), Drawing No. 1) and hydraulic rotary actuators (see Drawing No. 2, item (4)). The former are ordinary hydraulic actuators such as may be seen on any earth-moving equipment. The latter are special double-cylinder hydraulic rack and pinion rotary actuators capable of very high torque and able to hold position indefinitely at high load values. Because they act in parallel, they are synchronized by a shaft (see Drawing No. 4, item (41)). This ensures that the deploying arms on each side of the vehicle operate in unison.

Because manual control of the articulated blower deployment arms would require a high degree of operator skill, it is proposed that the control system for the arms be programmed to provide for the optimum movement path from the parked position to the deployed position. Also, it is recommended that the vertical oscillatory motion of the snowblower for clearing deep drifts be automatically controlled.

8. TURNTABLE

The upper section of the SNOWMASTER, complete with elevation wedge, horizontal deflector wedge, blower system, control cab, engine room and accommodation, is rotatable, while the flatbed underframe and trucks remain stationary, with the truck wheels maintaining continuous rail contact. Rotation is accomplished by means of an hydraulically-operated turntable (see Drawing No. 3, Section AA). The function of this mechanism is first to raise the upper section of the vehicle and second to rotate it.

Raising the upper section of the vehicle clear of supports on the underframe located over the centres of the two trucks is necessary prior to rotation. The lifting is accomplished by a large hydraulic ram located at the centre of rotation. When raised, the upper section will be supported by a volume of pressurized oil trapped in the cavity of the ram. This effectively provides an almost frictionless hydraulic "footstep" bearing on which the upper section of the vehicle may be rotated. Rotation is accomplished by means of a large gear and pinion. The gear (item (27)) is of large diameter and mounted rigidly

on the underframe, while the pinion is driven by a small hydrostatic motor mounted on the rotating section. During the lifting operation, there will be some axial displacement of the pinion relative to the gear; however, adequate meshing of the gear teeth will be ensured by making the face width of the pinion somewhat larger than that of the gear.

The SNOWMASTER will be self-propelled by means of either a hydrostatic or electric transmission. A complication in the arrangement of power conductors due to the turntable feature was solved in the following way. In the option shown, the transmission system for the main propulsion is hydrostatic, with the power unit in the rotating part and the traction motors on the trucks supporting the underframe. The only means of routing power to the traction motors is through the rotating turntable mechanism. To accommodate this requirement, the turntable (Drawing No. 3, Section AA) is fitted with a rotating hydraulic manifold (item (30)). This is the equivalent of slip rings in an alternative electrical transmission. It conveys the pressurized hydraulic transmission fluid from the supply hoses across the rotating journal of the turntable by means of a system of annular grooves and seals on a rotating pintle. From this manifold, the fluid is conducted by tubes fixed in the centre of the ram down to the base of the underframe, whence it is conducted to the traction motors by means of flexible hoses. The manifold also conveys pneumatic energy for the braking system.

If the option of electrical transmission were chosen, then electrical power for the traction motors would be transmitted using slip rings and conductors similarly routed through the turntable.

When rotation is completed, the upper section is lowered onto the underframe supports, at which time it is locked in position by means of the hydraulic locking cylinders (item (21) shown on Drawing No. 1.

9. PROPULSION SYSTEM

The SNOWMASTER is equipped with an on-board self-propulsion system intended for "hostling" purposes. This may be either electrical or hydrostatic.

The hydrostatic system is as illustrated on the various drawings. It consists of a variable-capacity engine-driven pump which operates in closed circuit with a fixed-capacity traction motor and gearbox assembly mounted on one of the trucks. This is shown in Sections BB, FF and GG on Drawing No. 3.

The traction motor/gearbox assembly is mounted on one of the axles, the torque reaction being transmitted through a link which connects the assembly to the bolster of the truck.

In the hydrostatic transmission described, the transmission ratio is infinitely variable. It is possible to control the speed of the vehicle together with the direction of motion, by using only the variable capacity over-centre control on the engine-driven pump, while keeping the engine speed constant. The engine may, therefore, also be used to drive an alternator at constant speed.

A unique feature of the hydrostatic transmission is that it is able to develop full torque at the traction wheels while these are turning at very low speed (to zero). It does this by virtue of the variable transmission ratio which can be made to approach infinity by reducing the pump capacity to zero. This means that by using the low-powered propulsion engine (150 hp), the vehicle can be inched along the track at very low speed while maintaining very high tractive effort, an ideal situation for snowblowing duties. The attendant locomotive would, therefore, be relieved of this duty, making it unnecessary to use the relatively high-powered locomotive engine for this very low-powered activity.

It would be possible to provide an electric transmission if this were the preferred option. The hydrostatic transmission was chosen partly because of its apparent suitability for the service, the compactness of the units, and the simplicity of the control; and partly because the many other functions of the SNOWMASTER are most readily powered hydraulically and it was thought to be desirable to maintain a consistency in the various drive systems.

10. HYDRAULIC POWER UNITS

The vehicle is powered by two engines, one of 635 hp and the other of 147 hp. Basically, these provide the power for snowblowing and propulsion, respectively. In addition, they provide the power for all of the auxiliary systems. They are located in a compartment at the rear of the rotating upper section of the vehicle.

The 147 hp main propulsion engine is run at constant speed while in service. In addition to its propulsion duties, this engine is used to provide power for auxiliary equipment which is only required intermittently and never when the engine is used for propulsion. These auxiliary systems include the turntable hydraulic lifting ram, the turntable drive, the turntable wedging cylinders, the flanger-deploying actuators, and the variable-geometry horizontal deflector wedge of the plowing surfaces. In addition, a drive for an alternator is taken off the front end of the engine.

It is anticipated that the main propulsion engine would be run continuously to provide the hotel services to the SNOWMASTER through the alternator.

A schematic arrangement of the hydraulic system is shown on Drawing No. 10. Note that the propulsion engine (item (1)) drives two pumps through a splitter gearbox mounted on the flywheel housing of the engine. One pump (item (3)) is a variable-capacity unit with a manual control used for propulsion only and in closed circuit with the traction motor (item (4)). The other pump (item (5)) is also a variable-capacity unit but is fitted with a pressure compensator control which automatically adjusts the capacity to limit the pump delivery pressure to a maximum value. This pump is used to provide power to the various auxiliary systems mentioned previously. Normally these systems are at standby and the valves (items (25)) are closed. This means that the pump is "dead headed" normally. In this condition, the pressure compensator will reduce the pump capacity to almost zero when it will be merely keeping the system pressure up to its maximum value ready for immediate use, while providing the natural hydraulic internal leakage losses. While at standby duty, this pump will be working at almost zero power and thus put a negligible load on the engine.

The opening of the various control valves for the auxiliary systems, when they are required, will immediately cause the automatic capacity control to stroke the pump and thus draw energy from the engine for operating the systems. When each operation reaches completion, signalled by mechanical stops which limit the motion, or by manual centring of the appropriate control valve, the pump capacity will again automatically return to standby duties while maintaining the system hydraulic pressure at a predetermined maximum value.

It is of interest to examine the operation of the turntable hydraulic lifting ram. When at rest, the control valve (item (22)) vents the hydraulic lifting ram to the tank. The pressure of fluid in the ram is therefore zero. When lifting is required prior to a rotation procedure, the valve (item (22)) is moved to expose the ram to the pressurized hydraulic fluid from the pump. The ram will, therefore, raise the bulk of the upper section of the vehicle from the underframe. This process will continue until the ram reaches the limit of its motion at a mechanical stop. At this point, the pump capacity will reduce while maintaining maximum pressure in the hydraulic ram and sustaining the SNOWMASTER in the raised position. The valve (item (22)) will be left in its open state while rotation is performed by means of the hydrostatic motor (item (10)). At the completion of the rotation, the valve (item (22)) will be closed, allowing the pressurized fluid in the ram to drain to the tank through a restrictor which will limit the speed of descent.

The speed of rotation will be controlled by restrictors (items (26)) in the lines leading to the turntable drive motor.

The operation of the turntable wedging cylinders, the flanger and the variable geometry of the plow is simple to understand from the diagram and need not be elaborated upon. In the three latter cases, the systems are hydraulically locked in position by means of pilot-operated cross-over check valves (item (20)), when the control valves (item (25)) are centred.

Power for the snowblower system is provided by a second engine of 635 hp. Again, a number of auxiliary systems are driven by the engine. These are all open circuits related to the blower system, and include the deployment arm actuators, the blower wing actuators, and

the blower casing drives. The hydraulic circuit diagram shown on Drawing No. 10 shows that the engine drives four hydrostatic pumps (items (6), (7) and (8)) through a splitter gearbox fitted on the engine flywheel housing.

The auger drive motor (item (13)) receives hydraulic fluid from the variable-capacity pump (item (7)). The speed of the auger is adjustable by means of the manual pump capacity control.

The same description fits the drives for the twin blowers consisting of the two pumps (item (6)) connected in open loop to the blower motors (item (12)).

The blower deployment arm actuators are driven at constant speed by a fixed-capacity double pump (item (8)). In addition, the associated auxiliary systems such as the blower wings and the blower casings draw power from this pump. The various systems are activated by manual operation of the various control valves (items (25), (27) and (28)).

The schematic hydraulic circuit shown on Drawing No. 10 is only intended to give basic information to those not familiar with this type of system. An actual system for the SNOWMASTER will require some elaboration.

11. OPERATOR'S CAB

The operator's cab is shown on Drawing No. 9. It has accommodation for five crewmen: an engineman, snowplow foreman, two maintenance-of-way employees and a conductor, and will contain all the engineman's controls as well as all the other operating controls.

It will be possible to remotely control a coupled locomotive and thus the cab will be of the locomotive type with adequate rearward vision.

The driver's cab will be located immediately above the variable-geometry lateral deflector wedge of the snowplow. However, it may be protected from flying snow thrown up by the plowing surfaces by a horizontal apron projecting over the top of the movable wedge.

Access to the cabin will be gained by an inside stairway located immediately to the rear of the cabin deck (see Drawing No. 1). An emergency door (item (11)) will give egress at cabin platform level.

12. CREW ACCOMMODATION
Drawing Nos. 1 and 2

Accommodation for the snowplow crew is provided to the rear of the vehicle. Access to it is available from the caboose-type rear platform via the engine room. The crew may also pass from the control cab to the crew quarters inside the body of the vehicle. Because of the caboose-type rear platform, the crew may pass from the SNOWMASTER to the first locomotive unit without descending from the train.

Facilities provided in the accommodation include a hotplate, refrigerator, sink, washroom/toilet, storage lockers and dining table. It would also be possible to include fold-away bunks if these were required.

13. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

The design, which has been described in some detail together with the proposed arrangement drawings, is considered to be sufficient to establish the feasibility of the SNOWMASTER concept in its general principles. However, much work is still to be done in the design stage before it would be possible to complete plans for actual manufacture.

There are many systems aboard SNOWMASTER which pose practical (though by no means insurmountable) problems. Their resolutions are a matter of routine design process. A very important consideration which any plan to proceed to a prototype must recognize is the degree of confidence and efficiency that could be placed on the satisfactory functioning of these systems.

In addition, it is very possible that in a vehicle having the sophistication and capability expected of SNOWMASTER to deal with adverse weather conditions, its powerful engine capacity and its hydraulic systems, there may be a desire to further expand its possible uses. For example, the presence of the hydraulic system suggests the addition of hydraulically-operated power tools for track maintenance. The presence of the blower deployment arms, which are reminiscent of a

front-end-loader, suggest a detachable blower and the provision of a hoist, etc.

ith these remarks in mind, the following areas of research are recommended for further consideration.

13.1 Blower

The deployment of the blower by means of articulated arms poses a problem in control. The blower must be raised from its parking place behind the control cab and routed over the roof of the cab to its final operating position in front of the plow. This manoeuvre may require a high degree of operator skill and there would always be a risk of error and resulting possible damage to the SNOWMASTER itself; or to other equipment such as overhead wires, bridges, etc. It is suggested that some method be sought to remove the need for a high degree of operator skill in the deployment of the snowblower, such as automatic programming of the hydraulic actuators, or a guide track for the blower which will keep it as low as possible while negotiating its path over the roof of the control cab to its final operating position.

A further control feature which would cause the blower to oscillate vertically while clearing deep snow drifts may also be desirable.

13.2 Forward Snowblowing Speed

The power drawn by the blower depends on various things. First, the consistency and density of snow are highly variable, both having a significant effect on the magnitude of the required power. In addition, the rate of advancement of the blower into the snowbank is a critical factor in the satisfactory use of available power. It is recommended, therefore, that an automatic control be developed which will optimize the speed settings of blower and forward advancement in such a way as to make the most efficient use of available energy, and at the same time make it easier for the operator to control the vehicle.

13.3 Geometry of Snowplowing Surfaces

As was mentioned in the previous text, the requirement for variable geometry in the plowing surfaces precludes the use of more conven-

tional, and perhaps more efficient, plowing surfaces. The plow consists basically of two wedges: an elevation wedge and a deflector wedge.

By making some reasonable assumptions, the passage of snow over the elevation wedge can be analyzed fairly easily. However, the same cannot be said for the deflection wedge without making some relatively sweeping assumptions. It would, therefore, be desirable to attempt a more rigorous analysis of the dynamics of SNOWMASTER's plowing system and at the same time carry out a practical experimental program using models.

As a part of the worldwide research in snowplowing technology, it would be desirable to investigate means of reducing the friction between the snow and the plowing surfaces by means of special paint or coating such as heavy molecular weight polymer (e.g. Cadillac No. 900 or 1900 Polymer). Reduction in the coefficient of friction would result in less impact force on the plow due to forward motion and also more efficient snow-clearing action.

13.4 Switch Broom

It was not possible to accommodate a conventional switch broom on the SNOWMASTER and time did not permit the development of a suitable alternative.

The addition of a switch broom would improve the flexibility of the vehicle and enhance its value as a fully-equipped snow-clearing system.

Alternative designs of switch broom should be considered for inclusion in the system, including the use of air or gas jet equipment.

13.5 Outriggers

While executing the rotation of the SNOWMASTER for plowing in the reverse direction, only a certain amount of imbalance in the rotating part can be tolerated without risking derailment.

To increase the tolerance to imbalance, it may be desirable to consider the use of hydraulically-deployed outriggers for the turning operation.

APPENDIX A

POWER REQUIREMENTS FOR PLOWING OPERATION

Rigorous mathematical analysis of the dynamics of snow clearing with the plow geometry used on SNOWMASTER is quite complex and outside the scope of this study. However, by making some broad assumptions the problem has been briefly addressed.

Considering first the elevation wedge (see Figure 4a). As the blade advances into the snow cover, the snow sheet mounts the blade. Ideally, in the absence of friction and assuming no distortion of the snow sheet, the velocity of the sheet relative to the blade would be the same as the forward speed of the plow. The presence of friction resistance will, however, tend to reduce the relative value of speed.

If it is assumed that there is no attendant change in density of the snow, the continuity would require the snow sheet to become thicker as it traverses the blade. Further, it is assumed that interactive forces between snow particles may be neglected without introducing significant error.

The correction factor, C, is used to express the exit velocity of the snow sheet from the blade. That is, if the forward velocity of the plow is V, then the relative exit velocity from the plow surface is CV.

The following analysis gives a possible method of evaluating C.

Figure 4 shows the profile of the elevation wedge. To simplify the calculation, the problem has been inverted by imposing on the system a velocity equal to the forward velocity of the snowplow, but in the opposite direction. This has the effect of bringing the plow to rest and imposing on the snow sheet a velocity equal in magnitude to the velocity of the plow but in the opposite direction. Dynamically, the problem has not been changed by this manoeuvre.

Referring to Figure 4a, it is seen that in passing over the surface of the elevation wedge, the snow sheet experiences a change in

momentum. This change is partly due to a change in direction and partly due to a reduction in velocity due to frictional resistance.

The following symbols are used:

V_1 = velocity of advance of snowplow

V_2 = velocity of snow over surface at leading edge of elevation wedge

V_3 = velocity of exit of snow sheet from wedge surface

A_1 = cross-sectional area of plowed snow

ρ = mass density of snow

μ = coefficient of friction of snow on surface of wedge

α = angle of attack

l = length of wedge surface in direction of travel

A = cross-sectional area of snow sheet on wedge surface

C = ratio of exit velocity to velocity of plow, i.e. $C = V_3/V_1$

The rate of mass transfer is expressed as $VA\rho$. In the figure the change in velocity is represented by the vector $\overrightarrow{CB}$.

To ease the calculation, the change in momentum across the elevation wedge has been considered in two phases. Phase one involves a change in direction due to the deflection of the wedge. There is a consequent reduction in linear velocity of the snow sheet due to one component of frictional resistance. The latter is caused by the normal impact force applied by the elevation wedge causing the change in direction of the snow sheet. Phase two involves a change in linear velocity over the length of the elevation wedge caused by a second component of frictional force together with tangential force; both due to the bodily weight of snow on the surface of the elevation wedge.

Considering phase one (Figure 4b), the initial change in velocity due to directional change is represented by the vector $\overrightarrow{CD}$. The magnitude of $\overrightarrow{CD}$ is expressed:

$$|\vec{CD}| = 2\ V_1 \sin \alpha/2 \qquad (1)$$

The accelerating force, F_1, in the direction of $\vec{CD}$ is given by multiplying this value by the mass flow rate, $\rho A V_1$, i.e.

$$F_1 = 1\ \rho A V_1^2 \sin \alpha/2 \qquad (2)$$

The normal force, F_2 (in the direction CE) would be expressed:

$$F_2 = F_1 \cos \alpha/2$$

and substituting for F_1 from equation (2):

$$F_2 = 2\ \rho A V_1^2 \sin \alpha/2 \cos \alpha/2$$

therefore:

$$F_2 = \rho A V_1^2 \sin \alpha \qquad (3)$$

The frictional resistance due to the normal force, F_2, is determined by multiplying the expression for F_2 in equation (3) by the coefficient of friction, μ, of snow on the wedge surface. The resulting tangential force will equal the initial rate of change of momentum along the surface of the wedge occurring at the leading edge of the wedge. Thus, the velocity of snow over the wedge surface at the leading edge of the wedge may be determined by equating this force to the rate of change of momentum of snow, i.e.

$$\mu \rho A_1 V_1^2 \sin \alpha = \rho A_1 V_1 (V_1 - V_2)$$

therefore:

$$\mu V_1 \sin \alpha = V_1 - V_2 \qquad (4)$$

Considering now phase two and referring to Figure 4c, an elemental section of the snow sheet is considered. Ignoring forces of interaction between snow particles, the tangential forces acting on the element due to gravitational and frictional forces may be equated to the rate of change of momentum. Thus:

$$\rho A\, V\, dV = -\left[\mu \rho g\, A \cos\alpha\, dx + \rho\, g\, A \sin\alpha\, dx\right]$$

therefore: $$V\, dV = -\, g\, \left[\mu \cos\alpha + \sin\alpha\right] dx$$

and integrating both sides:

$$\frac{V^2}{2} = -\, g\, \left[\mu \cos\alpha + \sin\alpha\right] x + c$$

At $x = 0$, $V = V_2$. Therefore: $C = \frac{V_2^2}{2}$

therefore: $$\frac{V^2}{2} = -\, g\, \left[\mu \cos\alpha + \sin\alpha\right] x + \frac{V_2^2}{2}$$

At $x = \ell$, $V = V_3$.

therefore: $$\frac{V_3^2}{2} = -\, g\, \left[\mu \cos\alpha + \sin\alpha\right] + \frac{V_2^2}{2}$$

therefore: $$V_3 = \sqrt{V_2^2 - 2g\, \left[\mu \cos\alpha + \sin\alpha\right] \ell} \qquad (5)$$

From equation (4):

$$V_2 = V_1\, (1 - \mu \sin\alpha)$$

and substituting this result in equation (5) gives the value of V_3, i.e.

$$V_3 = \sqrt{V_1^2\, (1 - \mu \sin\alpha)^2 - 2\, g\, \left[\mu \cos\alpha + \sin\alpha\right] \ell} \qquad (6)$$

The expression for the ratio C may now be obtained by dividing equation (6) by V_1. Thus,

$$C = \frac{V_3}{V_1} = \sqrt{(1 - \mu \sin\alpha)^2 - \frac{2g}{V_1^2}(\mu \cos\alpha + \sin\alpha)\ell} \qquad (7)$$

It is of interest to note that the value of C will be zero when the velocity, V_1, of the plow reaches a certain minimum value. This will occur when the following equation is satisfied:

$$V_{MIN} = \frac{\sqrt{2\ g\ (\mu \cos\alpha + \sin\alpha)\ \ell}}{(1 - \mu \sin\alpha)}$$

Below this speed, the snow will not have sufficient momentum to clear the surface of the elevation wedge and the snowplow would be ineffective.

Assigning practical values to the various parameters, it is now possible to calculate the probable values of the ratio C and the minimum velocity V_{MIN}. The following values have been used for the SNOWMASTER:

$$\mu = 0{,}16$$
$$\alpha = 35°$$
$$\ell = 8 \text{ ft.}$$

Note that the value of μ chosen for the coefficient of friction of snow on steel is the maximum range of values quoted by Croce[3] as being 0.03 to 0.16.

Table A.1 gives values of C and the relative velocity of exit V_3 for the elevation wedge of the snowplow.

TABLE A.1

V_1 (mph)	C	V_3(mph)
60	0.882	52.9
55	0.877	48.24
50	0.870	43.5
45	0.860	38.7
40	0.850	34.0
35	0.829	29.02
30	0.798	23.94
25	0.745	18.63
20	0.635	12.7
15	0.274	4.102
V_{MIN} = 14.304	0.0067	-

From the chosen parameters it would appear that the minimum plowing speed as far as the elevation wedge is concerned is approximately 14 mph. Below this speed the snow would merely accumulate in front of the wedge.

Having determined a method for calculating the value of the ratio of the speed of the plow and the relative speed of exit, it is now possible to calculate the power required to advance the elevation wedge through the snow layer.

The method used is a development of the "AUFWICKLUNGSTHEORIE" used by Croce.[1]

Referring to Figure 5, it is noted that as the wedge advances through the snow a distance, S, a particle of snow in the snow layer will be displaced in the direction of travel, a distance X, where:

$$X = S - CS \cos \alpha$$

Differentiating this, the forward velocity imparted to the snow is expressed:

$$\frac{dx}{dt} = \frac{ds}{dt} (1 - C \cos \alpha)$$

and since $dx/dt = V_x$ and $ds/dt = V_1$, the last equation may be written:

$$V_x = V_1 (1 - \cos \alpha) \qquad (9)$$

where: V_x = forward velocity imparted to snow

V_1 = forward speed of plow

C = ratio of speeds as given by equation number (7).

The forward thrust required is calculated by expressing the rate of change of momentum of the snow. If A_1 is the cross-sectional area of snow being plowed, then the mass flow rate is expressed as $\rho A_1 V_1$. The rate of change of momentum is expressed by multiplying the latter value by equation (9). This is equal to the required thrust. Thus, the forward thrust, F_x, is expressed as:

$$F_x = \rho A_1 V_1^2 (1 - C \cos \alpha) \qquad (10)$$

The power required is expressed by multiplying the value of F_x by the forward velocity of the vehicle. If power is represented by P, we have:

$$P = F_x V = \rho A_1 V_1^3 (1 - C \cos \alpha)$$

If pound force, foot, second units are used, then the horsepower required for plowing with the elevation wedge will be expressed as follows:

$$hp = \frac{\rho A_1 V_1^3 (1 - C \cos \alpha)}{550} \qquad (11)$$

Assume specific weight of snow = 15 lbs/ft^3, then ρ = 15/32.2 = 0.466 slugs/ft^3.

Assuming depth of snow is 1 ft and having a plow wedge width of 10 ft, then A = 10. The angle of attack, α, is 35°. Table A 2 gives values of C, F_x and horsepower for various plow speeds.

TABLE A.2

Vehicle Speed (mph)	C	F_x (lbs force)	hp
60	0.882	10,009	1,602
55	0.877	8,536	1,252
50	0.870	7,192	959
45	0.860	5,978	717
40	0.85	4,893	522
35	0.83	3,940	368
30	0.798	3,120	249
25	0.746	2,441	163
20	0.635	1,923	102
15	0.274	1,749	70
(V_{MIN}) 14.304	0.0067	2,038	78

It must be emphasized that Table 2 refers only to the elevation wedge. The treatment of the horizontal deflection wedge is more difficult, since the snow will reach it after it has left the elevation wedge and will be in a free fall trajectory. Considering the resulting variations in angle of impact of the snow with the deflection wedge surface, a mathematical analysis of the snow dynamics in the latter case would be very complex and it is doubtful if any meaningful result would be obtained in view of the many necessary assumptions that would have to be made.

Another important consideration is the speed of plowing. If the speed is too slow, then the trajectory of the plowed snow after leaving the elevation wedge would be so low that much of the snow would fall onto the upper platform of the elevation wedge before reaching the surface of the horizontal deflection wedge.

By using simple physics, it is possible to get some idea of the minimum plowing speed. The relative speed of the snow sheet leaving the elevation wedge is calculated using the factors C in Table 1. Table A.3 lists these speeds against the appropriate vehicle speeds.

TABLE A.3

Vehicle Speed		Speed Reduction Ratio (C)	Relative Exit Velocity (VC(fps))	Angle of Attack (α)
mph	fps			
60	88	0.882	77.6	35°
50	73	0.870	63.5	35°
40	59	0.85	50.2	35°
30	44	0.798	35.1	35°
20	29	0.635	18.4	35°

If wind resistance is ignored, then the trajectory equation may be used to plot the path of the snow relative to the snowplow, after leaving the elevation wedge.

The trajectory equation is as follows:

$$y = x \tan \alpha - \frac{gx^2}{2C^2 V^2 \cos^2 \alpha} \qquad (12)$$

where: y = vertical coordinate above platform
x = distance travelled
α = angle of attack
V = velocity of plow in ft/sec.

The trajectories of the snow leaving the elevation wedge are shown in Figure 6. It is desirable that all the snow leaving the elevation wedge come in contact with the deflection wedge surface before dropping onto the wedge platform where it may come to rest and accumulate. The higher the trajectory, the more likely the latter effect will be avoided. This means that it is desirable to plow at as high a speed as possible up to the limit of 60 mph. Certainly, the trajectory plots indicate that perhaps the plowing speed should not be less than 22 mph or thereabouts.

It should be borne in mind that the coefficient of friction of 0.16 for snow on steel used in this report was that recorded as a maximum by Croce.[3] It is probable that this figure may be reduced greatly by the use of special coatings such as special paints or a layer of polymeric material. Reduction in the friction would be beneficial in reducing the impact on the plowing surfaces and thus the wear and tear. Also, there would be a reduction in the power requirement from the locomotive.

It is of interest to note from equation (12) that the trajectory of the snow sheet is unaffected by the snow density. The effect of friction could be further reduced if the profile of the wedge were made to just clear the trajectory of free fall starting from the first change in direction of the snow sheet at the tip of the wedge, and for a specific vehicle speed. When plowing at this speed, the snow sheet would only contact the elevation wedge at the tip. After the consequent change in directon, the snow would be in free fall until coming in contact with the horizontal deflection wedge. Thus, the only point of contact with the elevation wedge would be at the tip. Thereafter there would be no further contact with the elevation wedge surface and the effects of friction would thereby be reduced.

With regard to the power required by the deflection wedge, this is difficult to predict without extensive mathematical analysis as mentioned previously. However, it is probably of the same order of magnitude as the power required by the elevation wedge. A rough assessment of the power required by the plowing surfaces may thus be made by doubling the power reqirement for the elevation wedge. Using this method and referring to Table 2, it may be determined that at a speed of 25 mph, while plowing 1 foot of snow of specific weight of 15 lbs per ft^3, the power required for plowing only would be approximately 2 x 163 = 326 hp. To this must be added the power to propel the vehicle and the locomotive itself, together with any additional service being provided.

APPENDIX B

SNOWBLOWER DESIGN PROCEDURE

The design procedure for the snowblower was adopted with little modification from a paper by L.B. Walker (Sicard Inc.) (date of publication unknown). With the permission of the SAE and the author, the paper is reproduced in full in this appendix and is followed by the calculations made for the SNOWMASTER snowblower equipment.

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Design and Development of Mechanical Snow Blowing Equipment

L. B. Walker
Sicard Inc.

ABSTRACT

The design development of a snow blower of the conveyor impeller type is the subject of this paper. The mechanical aspects are conventional, but the calculations involve the selection of dimensions for components based on snow as a unique and variable material to be handled by a typical machine.

The machine discussed here moved 20 tons of snow per minute, throwing it a distance of 150 ft. The conveyor section consists of double screws, 20 in. dia, turning at 400 rpm and requiring 44.5 hp. The impeller, at 550 rpm, is 42 in. dia, requiring 265 hp.

The configuration of various blower designs, with the powerplant integrally mounted or separately truck mounted, and with the impeller either separate or integral with a single conveyor, are clearly illustrated.

THERE ARE three principal methods of mechanical snow removal: plows, blowers, and sweepers. The design of these machines is conventional from the standpoint of machine design, but the unique part of the problem is concerned with the characteristics of snow and the power necessary to move it. The subject given most attention in this paper, therefore, is the design of a blower type snow removal unit.

Calculations giving a general idea of the factors involved will be examined for each component and the configurations of snow blowing and sweeping equipment will be described.

The struggle against snow, so necessary today to maintain traffic circulation at all times on the roads, railway rights of way, and airports, meets with great difficulties that have not been entirely overcome nor even precisely understood.

Snow is in fact a very variable material. It may be a powder light and without cohesion, with a specific weight of 5 lb/cu ft or it may be packed into almost solid ice, weighing 60 lb/cu ft. Most often, however, we expect to move snow whose specific weight varies from 10 to 40 lb/cu ft.

An important factor in snow clearing is the cohesion of the snow, which becomes stronger as the grains become smaller. An increase of density corresponds to an increase of hardness. The connecting strength, which must be overcome to remove the snow from the mass, is extremely variable, being almost zero for new fallen snow and high in the case of ice.

The physical characteristics of snow that we should consider in the construction of a snow plow are the following:

1. Specific weight: from 10 to 40 lb/cu ft.
2. Crystalline structure.
3. Cohesion, or the adhesion between the particles.

OPERATIONAL THEORY

The operation of a snow plow can be compared to a pump in that it is able to take in a moving mass of snow, impress on it a certain acceleration, and reject it with a considerable velocity. Since snow is a plastic material, its deformation can be produced in two different ways. If the acting forces are relatively weak and operate slowly, the deformation of the snow is accomplished without breaking its cohesion. If, on the other hand, rapid movements are applied to the snow, internal friction is produced (snow on snow), and external (snow on different parts of the snow plow) friction as well.

If the parts of the apparatus that penetrate the snow are made in such a way that their movement applies pressures to the snow, it produces friction and compression.

In the construction of snow plows, compression of the snow should be avoided as much as possible, and a progressive acceleration should be produced to the point where the load is ejected. To accomplish this, then, the snow plow should carry out two distinct operations:

1. Separate the particles of snow from the mass.
2. Throw the snow.

Theoretical considerations, tests on models, and also experience furnished by machines in service have shown that it is sensible to execute the two parts of the work, separation and evacuation, by two different mechanisms (Fig. 1). One

can thus benefit at the same time from the advantages of the screw (helical conveyor) and of the turbine.

GENERAL DESIGN PROBLEM

We have the following data:

1. Quantity of snow for removal: 40,000 lb/minute.
2. Distance of throwing: 150 ft.
3. Width of swept path: 100 in.
4. Mean height of snow bank: 48 in.
5. Physical characteristics of snow:

(a) Specific weight: for purposes of calculation, a value of 30 pcf. $= 0.5\ gr/cm^3$

(b) Resistance of snow, lb/sq ft.

The value of the resistance of snow has been determined with the help of experimental information obtained from tests carried out in Germany in 1941-1945 (Fig. 2).

The resistance of snow was determined with the help of a cone at an angle of 75 deg. The cone weighed 210 grams and was launched from a height of 40 cm (Fig. 2).

For hard snow, the cone pushed down from 1-3 cm. This kind of snow corresponds closely to the snow which we wish to adopt for purposes of calculation.

Table 1 is taken from statistics established in Canada in the course of winters 1947-1950 by Messrs. Pearce and Gold of the National Research Council. This table gives us the resistance of snow in various parts of the country.

From the values obtained in the tests made in Germany and from statistics obtained from the National Research Council, we have adopted a value of snow resistance as follows: 300 gr/sq cm, or about 4 lb/sq ft.

DETERMINATION OF SPEED OF TRUCK

Calculations for truck speed are as follows:

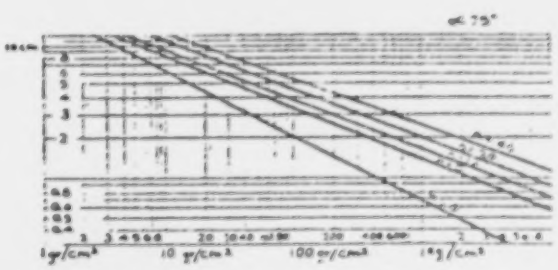
1. Section of snow facing the machine (Fig. 3): For the area,

$$\frac{48'' \times 100}{144} = 33.3 \text{ sq ft}$$

For output in cfm:

$$Q = \frac{40{,}000 \text{ lb} \times \text{cu ft}}{\text{minutes} \times 30 \text{ lb}} = 1333 \text{ cfm}$$

$$= 38{,}400 \text{ cu in./sec}$$



MADE FROM TESTS CARRIED OUT IN GERMANY USING A 75° CONE.

OUR CALCULATIONS ARE MADE FOR 30 Lbs/FT³ SNOW
THIS SNOW IS CONSIDERED AS IN A HARD STATE.
TESTING IN HARD SNOW
A) DROP HEIGHT: 40 cm
B) PENETRATION: 1 TO 3 cm
C) CONE WEIGHT: 210 gr
D) SNOW RESISTANCE: 500 gr/cm² (PENETRATION 3 cm)
THIS GIVES AN APPROXIMATE RESISTANCE OF 5 Lbs/in²

Fig. 2 - Snow resistance versus penetration curves

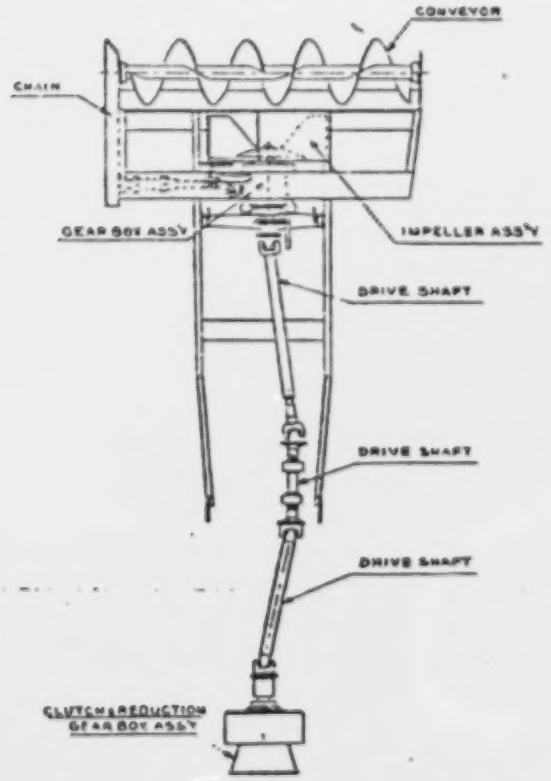


Fig. 1 - Rotary snow plow assembly planview

Table 1 - Regional Variances in Snow Resistance

Place	Resistance, gr/cm²
Ottawa	100-1000
Toronto	100-1000
Edmonton	50
Gander	100
Goose Bay	100

SOURCE: Canadian Snow Survey 1947-1950.

For speed of the truck:

$$Q = A \times V$$

where: Q = Output of snow, cfm
A = Section of snow facing machine, sq ft
V = Speed of truck, fpm

$$= \frac{1333}{33.3} = 40 \text{ fpm}$$

$$= 2/3 \text{ fps}$$

CALCULATIONS OF DIMENSIONS OF CONVEYOR

The conveyor should be capable of breaking up the snow and of channeling it toward the center of the turbine.

In order that the flow will be produced with the minimum of loss by friction, it is necessary that the particles of snow slide readily. The angle of attack of the helical conveyors with the direction of advance should not exceed a specified value corresponding to the nature of the snow and to the form and to the roughness of the surfaces. To avoid having the snow adhere to the surfaces of the conveyors, it has been demonstrated that this angle should be less than 45 deg.

BASIC CALCULATIONS - Dimensions of the conveyor may be calculated as:

1. Calculation of diameter of helical conveyors - The machine has two helical conveyors mounted on horizontal shafts. Each conveyor is formed from a series of screws, right and left, which permit the channeling of the snow toward the center of the turbine (Fig. 4).

If the machine works at full capacity and if the two conveyors work equally, each part of the conveyors ought to clear a quarter of the total output.

2. Discharge for each part of one conveyor - The discharge capacity is

$$\frac{38,400}{4} = 9600 \text{ cu in./sec}$$

In order to avoid too great a compression of the snow in the conveyors, we shall take a ratio:

$$\frac{\text{Pitch of screw}}{\text{Dia. of conv.}} = 1$$

4. Determination of helix angle (Fig. 5) - The formula for the helix angle is

$$\tan a = \frac{D}{\pi D} \quad \text{or} \quad a = 17.7 \text{ deg}$$

Since the angle obtained is less than 45 deg, a ratio of 1 is acceptable.

5. Thickness of snow per turn of conveyor.

6. In order to minimize the couple necessary to break up and displace the snow, we shall take a speed of rotation of 400 rpm.

7. Displacement of truck during 1 minute is 40 ft.

8. Thickness of snow per revolution is

$$\frac{40 \times 12}{400} = 1.2 \text{ in.}$$

9. Angular displacement to travel the distance of one pitch is

$$2\pi = wT \qquad (1)$$

10. Linear displacement of the snow when the conveyor makes one turn is

$$P = VT \qquad (2)$$

where: P = Linear displacement equal to one pitch of helix, 2R
R = Radius of conveyor
V = Speed of translation of snow
T = Time to travel one pitch
w = Speed of conveyor, radians/sec

Combining Eqs. 1 and 2, we obtain

$$\frac{2\pi}{P} = \frac{w}{V} \qquad (3)$$

$$Q = A \times V \qquad (4)$$

where: A = Section of circular annulus of snow formed in conveyor
Q = Discharge of snow in one part of conveyor, or 9600 cu in./sec
V = Linear speed of snow in the conveyor, in./sec

Combining Eqs. 3 and 4, we obtain

$$\frac{2\pi}{P} = \frac{w \times A}{Q} \qquad (5)$$

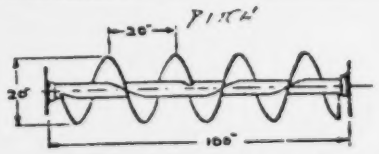


Fig. 4 - Conveyor dimensions

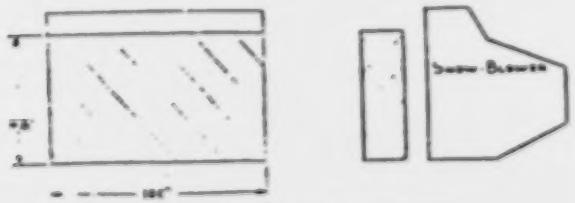


Fig. 3 - Dimensions of snow bank

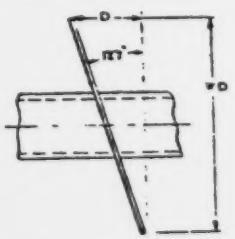


Fig. 5 - Helix angle

and the area of the circular annulus is $A = \pi\left[R^2 - (R - 1.2)^2\right]$

Finally we obtain an equation that permits us to determine the diameter of the conveyor:

$$\frac{2\pi}{P} = \frac{2\pi \times rpm \times \pi\left[R^2 - (R - 1.2)^2\right]}{60\,Q}$$

By replacing the terms by their values, we obtain the diameter of the conveyor as

$$\frac{2\pi}{2R} = \frac{2\pi \times 400 \times \pi(R^2 - R^2 + 2.4R - 1.44)}{9600 \times 60}$$

$$229 = 2.4R^2 - 1.44R$$

Hence we find that a radius of 10 in. would be acceptable and that the diameter of the conveyor would be 20 in. To determine the number of flutes on each part of the conveyor, we take the ratio between the diameter and the pitch of the screw equal to 1, so that we have

$$P = 20$$

$$N = \frac{L}{P}$$

where: N = Number of flutes

L = Length of one part of conveyor, or 50 in.

From this we obtain

$$N = \frac{50 \text{ in.}}{20 \text{ in.}} = 2\tfrac{1}{2} \text{ flutes}$$

and the number of flutes on the conveyor is

$$\frac{2\tfrac{1}{2} \times 100}{50} = 5 \text{ flutes}$$

Analysis of Forces Acting on One Flute of Conveyor - The conveyor should be capable of overcoming forces of cohesion of the snow and of the applied torque to break the snow from the mass. For purposes of calculation we shall replace the helical screw with circular plates that have an angle of attack equal to the angle of the helix (Fig. 6). We calculate as follows:

1. Resistance of snow is 4 lb/sq in.
2. Conveyor turns at 400 rpm.
3. Conveyor moves 1.2 in. of snow per revolution.
4. Volume of snow per flute per cycle is Height x Width x Thickness = 480 cu in.

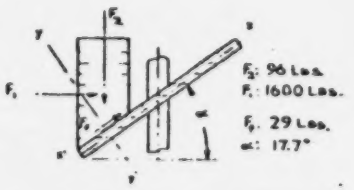


Fig. 6 - Snow cohesion forces

5. Resistance of the snow is

(a) Force parallel to the axis of the conveyor:

$$F_2 = 4 \times 20 \times 1.2 = 96 \text{ lb}$$

(b) Force in the direction of the snow plow:

$$F_1 = 4 \times 20 \times 20 = 1600 \text{ lb}$$

6. Value of the normal component is

$$F_y = F_1 \times \sin a + F_2 \cos a$$
$$= 1600 \times \sin(17.7) + 96 \times \cos(17.7)$$
$$= 485 + 91.5 = 576.5 \text{ lb}$$

Force of Friction - As the snow is being displaced in the conveyor, a force of friction is produced. Laboratory tests carried out in Germany and in Switzerland in 1945-1946 have demonstrated that the coefficient of friction between the particles of snow and steel plates can vary from 0.03-0.15, that is,

$$F_f = u \times F_y$$

Since the conveyor has been caculated for a minimum of compression, we shall take a coefficient of friction of 0.05:

$$F_f = 0.05 \times 576.5 = 29 \text{ lb}$$

This force is not considered in the calculations that follow.

Torque Applied to Break Up the Snow - Work necessary to overcome force F_2 when the conveyor makes one revolution, where P (pitch of screw) is 20 in., is

$$T_1 = F_2 \times P$$

$$T_1 = 96 \times 20 = 1920 \text{ lb-in.}$$

This work is done by the screw.

Work Necessary to Overcome Force F_1 - The formula is

$$T_2 = F_1 \times H$$

and the distance traveled by the truck per revolution of the conveyor is

$$\frac{40 \times 12}{400} = 1.2 \text{ in.}$$

$$T = 1600 \times 1.2 = 1920 \text{ lb-in.}$$

This work is done by the truck.

Power Required - Each part of the conveyor should move 10,000 lb of snow per minute. The snow enters the full length of the conveyor. The maximum distance to travel is 50 in. The particles of snow do not travel the same distance. Each part of the conveyor includes $2\tfrac{1}{2}$ flutes.

For purposes of calculation we shall divide the quantity of snow in three different ways, and we shall have three different distances, which will be calculated as follows:

Distance = Distance between part most distant from one flute and center of conveyor

Table 2 shows the three quantities of snow and the distances they must travel. The power necessary to displace these different quantities of snow is expressed by the formula:

$$hp = \frac{Q \times L \times F}{33{,}000}$$

where: hp = Power, hp
Q = Quantity of snow per minute of quantities A, B, C
L = Distance of displacement, or 10/12, 30/12, 50/12 ft
F = Material factor

Since the snow may have different densities, it will be more or less difficult to transport. By using a granular material that has a density equal to the average density of snow, we have adopted a value of 4. Using this value, we replace the terms of the formula and obtain the powers to displace quantities A, B, C.

Quantity A:

$$hp = \frac{4000 \times 50 \times 4}{33{,}000 \times 12} = 2.02 \text{ hp}$$

Quantity B:

$$hp = \frac{4000 \times 30 \times 4}{33{,}000 \times 12} = 1.21 \text{ hp}$$

Quantity C:

$$hp = \frac{2000 \times 10 \times 4}{33{,}000 \times 12} = 0.20 \text{ hp}$$

Hence we find that the power necessary is 3.43 hp, and we add 1 hp in order to take care of the drifts that may occur. Using this result, we calculate the total power necessary per part of conveyor as

$$3.43 + 1 = 4.43 \text{ hp}$$

The power necessary to break up and displace the snow will be transmitted to the conveyors with the help of a power chain. This power necessary to transmit to the conveyors is calculated as follows:

1. To displace the snow: 4.43 hp per part of conveyor.

2. We have four parts of the conveyor and therefore the total necessary power is

$$4 \times 4.43 = 17.72 \text{ hp}$$

3. To break up the snow, we estimate the work per flute as 1920 lb-in. per cycle.

Table 2 - Distances of Snow Travel

Quantity	Q, lb/minute	Distance, in.
A	4000	50
B	4000	30
C	2000	10
Total	10,000	

We have two helical conveyors. Each conveyor consists of five flutes. Hence:

1. Total work:

$$2 \times 5 \times 1920 = 19{,}200 \text{ lb-in./c}$$

2. Total power to break up the snow:

$$\frac{19{,}200 \times 400}{33{,}000 \times 12} = 19.4 \text{ hp}$$

3. Net power:

$$17.72 + 19.4 = 37.1 \text{ hp}$$

4. Total power required:

hp (net) x service factor

We calculate the service factor, presuming we have a conveyor that is not uniformly loaded and that the machine operates at 8-10 hr per day, as 1.2. Then horsepower required is

$$37.1 \times 1.2 = 44.5 \text{ hp}$$

THE IMPELLER

The impeller should be able to throw a mass of snow a distance of 150 ft. The snow enters at low speed and should be thrown out at high speed. Theoretically, the particles of snow being displaced in the turbine should not be given any tangential acceleration. The speed of rotation of the particles ought to be exactly equal to the peripheral speed of the turbine. The speed of rotation of the turbine should be equal to 550 rpm. We perform the following calculations.

1. Speed of the snow mass at the entrance of the turbine To calculate the useful power to displace snow 50 in. the length of the conveyors, the amount displaced is assumed to be 10,000 lb per minute on each part of the conveyor. The material factor employed in the power calculation is 4 and the useful power is

$$\frac{3.43}{4} = 0.857 \text{ hp}$$

2. Speed of entry of the snow in the collector apparatus is 2/3 fps.

3. Speed at the entrance of the turbine may be calculated as

$$hp = \frac{1 \times W(V_f^2 - V_i^2)}{2 \times g \times 550}$$

where: hp = Useful power = 0.857 hp
W = Quantity of snow per second = 10,000/60
G = Acceleration due to gravity = 32.2 ft/sec^2
V_f = Final speed (at entrance of turbine)
V_i = Initial speed (at entrance of collecting apparatus)

Replacing the terms of the equation by their numerical values, we obtain

$$0.857 = \frac{1 \times 10{,}000 \times (V_f^2 - 0.445)}{2 \times 32.2 \times 60 \times 550}$$

where: V_f = fps
Dia of impeller = 42 in.
Throwing distance = 150 ft
Discharge of snow = 40,000 lb/minute
Ideal angle of throwing = 45 deg

4. Speed of projection of the snow, when one does not take into account resistance of the air, is calculated by the formula:

$$R = \frac{V^2}{g} \times \sin(2\Theta)$$

where: R = Distance of throwing, or 150 ft
V = Speed of projection
Θ = Angle of throwing, or 45 deg
g = 32.3 ft/sec^2 from which $V = \sqrt{150 \times 32.2} = 69.5$ fps

In practice, it is impossible to throw the snow 150 ft with a speed of 69.5 fps because resistance of the air diminishes this distance of throw. Different tests carried out in Germany during World War II have shown that there is a big difference between theoretical speed and actual speed for a given throwing distance. A series of curves has been established for a German snow plow. Fig. 7 shows the difference between the actual curve and the theoretical curve.

The machine used in this project is similar to the German snow plow. With the help of Fig. 7, we have chosen a curve that will be understood to be between the theoretical curve and the experimental curve. From this curve, we shall obtain the throwing speed for a given throwing distance. The equation of the curve established for the calculation of this project is

$$R = \frac{V_r^2 \times K^2 \times \sin(2\Theta)}{g}$$

where K has the value of 0.7. Hence the value of the speed is

$$V_r = \sqrt{\frac{150 \times 32.2}{0.7}} = 99.5 \text{ fps}$$

Diameter of Impeller - Since the particles of snow are displaced along the blades, the discharge speed of the snow should be substantially equal to the tangential speed of the wheel:

$$V = \frac{\pi \times D \times N}{12 \times 60}$$

where: V = Tangential speed 99.5 ft/sec
D = Diameter of the wheel, in.
N = Wheel rpm, or 550 rpm

The diameter is

$$D = \frac{99.5 \times 60 \times 12}{\pi \times 550} = 42 \text{ in.}$$

We figure the minimum angle of opening of the discharge as follows: If we have six blades, we shall have an angle equal to

$$\frac{360}{6} = 60 \text{ deg}$$

This is the value of the inside radius of the maximum cylinder of snow that we can obtain in the turbine.

The particles of snow are subjected to the action of centrifugal force. For purposes of demonstration, we shall take a flat plate and analyze the displacement of a particle the length of this plate (Fig. 8). Note that the following relations hold only if the particle is displaced the length of a radial sliding plane and if there is no tangential acceleration.

We have, then,

$$F_c = mrw^2 = \frac{m d_2^r}{dt^2}$$

$$\frac{d^2 r}{dt^2} = rw^2$$

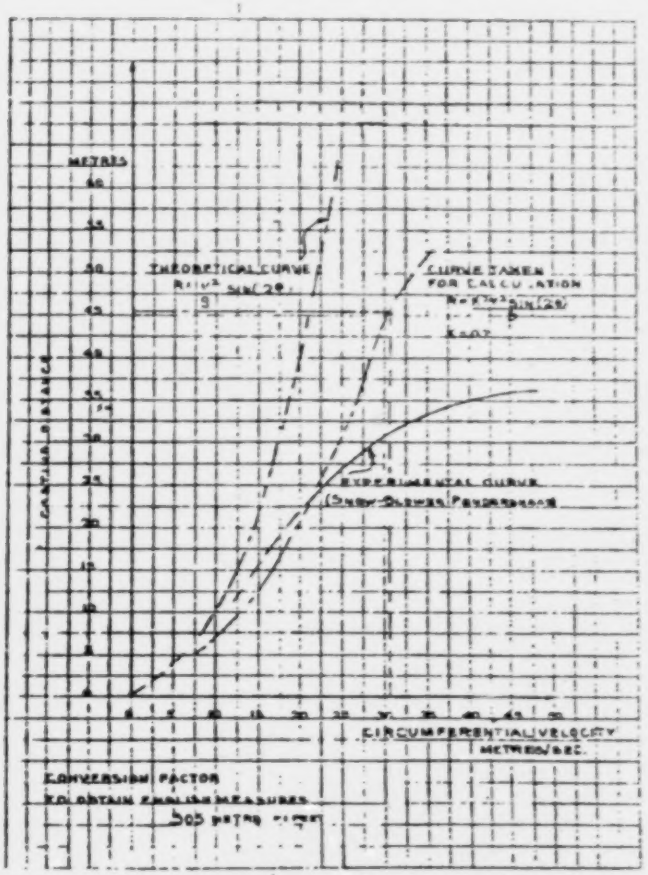


Fig. 7 - Casting distance versus circumferential velocity curve

SNOW IS COMPRESSED BEFORE IT IS CAST - HOW MUCH DOES CASTING INCREASE VOLUME?

Let us multiply the two sides of the equation by dr/dt:

$$\frac{d^2r}{dt^2} \times \frac{dr}{dt} = rw^2 \times \frac{dr}{dt}$$

We make some adjustments on the left side and define

$$\frac{dr}{dt} = u \left| \frac{d^2r}{dt^2} = \frac{du}{dt} \right.$$

and on substituting, we obtain

$$u \times \frac{du}{dt} = rw^2 \times \frac{dr}{dt}$$

$$\int u \times du = \int rw^2 \times dr$$

By integrating, we obtain the following relation:

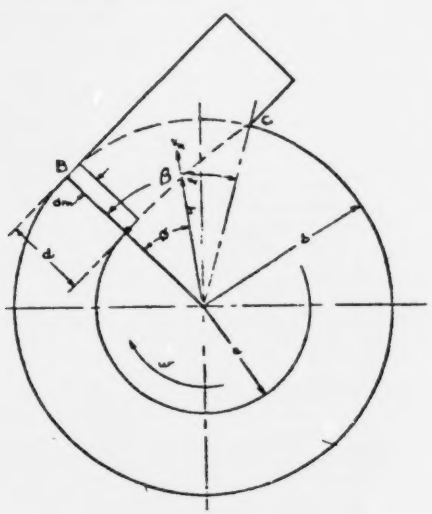
$$\frac{u^2}{2} = \frac{r^2 \times w^2}{2} + C$$

whence

$$\frac{dr}{dt} = \sqrt{r^2 \times w^2 + 2C}$$

We get the value of the constant, when $t = 0$, $dr/dt = 0$, $r = r_0$, as

$$2C = -r_0^2 \times w^2$$



W : TANGENTIAL VELOCITY : 995 Ft/sec.
V_R : RADIAL VELOCITY
b : IMPELLER RADIUS
ω : R.P.M. 1550

Fig. 3 - Motion analysis of a snow particle moving along impeller blade

Replacing the constant by its value, we have

$$\frac{dr}{dt} = w\sqrt{r^2 - r_0^2}$$

whence

$$w\,dt = \frac{dr}{\sqrt{r^2 - r_0^2}}$$

Now we make a new integration within the following limits: $t = 0$ to $t = t$, for $r = r_0$ to $r = R$ of the wheel. Hence,

$$\int_0^t w\,dt = \int_{r_0}^{r} \frac{dr}{\sqrt{r^2 - r_0^2}}$$

After integration we have

$$wt = \ln \frac{1}{r_0} \left(R + \sqrt{R^2 - r_0^2} \right)$$

But $wt = B$, so that we have

$$B = \ln \frac{1}{r_0} \left(R + \sqrt{R^2 - r_0^2} \right)$$

whence

$$e^B = \frac{\left(R + \sqrt{R^2 - r_0^2} \right)}{r_0}$$

Given the relation

$$e^B = \cosh B + \sinh B$$

we can say that

$$\cosh B = \frac{R}{r_0}$$

and for purposes of calculation, we shall adopt this last relation.

Note that the preceding expressions have been taken from Refs. 1 and 2.

We now calculate the ratio between the radius of the wheel and the interior radius as

$$C = \frac{r_0}{R}$$

We know that the radius of the wheel is

$$\frac{42}{2} = 21 \text{ in.}$$

According to the following relation, we have

$$\cosh B = \frac{R}{r_0} = \frac{1}{C}$$

To find the value of r_0, we proceed as follows: We know the angle is 60 deg. Then

$$\cosh(60°) = 1.60379$$

and $$C = 0.624$$

Consequently,

$$r_0 = C \times R$$

$$r_0 = 0.624 \times 21 = 13.1 \text{ in.}$$

and the maximum thickness of snow capable of passing through the opening of the discharge is

$$R - r_0 = 21 - 13 = 8 \text{ in.}$$

Determination of Width of Impeller - To calculate the maximum absorption capacity of the turbine, we define the maximum capacity as the maximum volume of snow absorbed in 1 hr by a centrifugal wheel having straight blades. The maximum capacity is given by the following relation:

$$S = 60 \times N \times F \times T$$

where: S = Maximum capacity, cu ft/hr
N = rpm, or 550 rpm
F = Surface of circular annulus determined by R and r_0
T = Width of the centrifugal wheel

Hence:

$$F = \pi (R^2 - r_0^2)$$

$$= \pi \times R^2 (1 - C^2)$$

Making allowance for a possible loss by friction of 25% in the turbine, we have

$$S = 0.75 \times 60 \times N \times \pi \times T \times R^2 (1 - C^2)$$

Note that if the machine works at full capacity, snow weighing 30 lb/cu ft will be compressed 1.5 times its initial volume, and its specific weight will become then 45 lb/cu ft.

CALCULATION OF MAXIMUM CAPACITY

If we take a blade width equal to 10 in. and replace the terms by their numerical value, we obtain:

$$S = \frac{140 \times 550 \times 10 \times 441 \times (1 - 0.39)}{1728}$$

$$= 120{,}000 \text{ cu ft/hr}$$

or $$S = \frac{120.000}{60} = 2000 \text{ cfm}$$

The maximum capacity in lb/minute will be

$$2000 \times 45 = 90{,}000 \text{ lb/minute}$$

Suppose we wish to move 40,000 lb of snow per minute. The turbine can absorb 90,000 lb of snow per minute when the snow weighs 45 lb/cu ft. Then the width of wheel in our experiment is acceptable, and we have a width equal to 10 in.

To obtain the power absorbed by the snow in the turbine, we use the formula:

$$hp = \frac{1 \times W \times (V_f^2 - V_i^2)}{2 \times g \times 60{:}550}$$

where: W = Quantity of snow per minute absorbed by turbine, 40,000 lb/minute
V_f = Final speed at the outlet of the turbine, or 99.5 ft-sec
V_i = Speed at the entrance of the turbine, or 13.5 fps

Now replacing terms, we have

$$hp = \frac{40{,}000 \times (9900 - 182)}{64.4 \times 33{,}000} = 184 \text{ hp}$$

If we allow for a loss by friction (or from any other source) of 30% in the turbine, we shall have power "input" to the turbine equal to the following value:

$$\text{hp input} = \frac{184}{0.70} = 265 \text{ hp}$$

Power of the Motor - If we accept a mechanical return of 90%, we shall have a power output at the motor of:

$$hp = \frac{\text{Power input of turbine + power to chain}}{\text{Mechanical efficiency}}$$

or

$$hp = \frac{264 + 44.5}{0.90} = 308.5 \text{ hp}$$

SUMMARY ON CALCULATIONS

For purposes of calculation we have adopted a specific weight of snow, 30 lb/cu ft, and a resistance of 4 lb/sq ft. These data, adopted without being maximum values, have appeared satisfactory. In fact, a snow plow can work in near-ice whose resistance greatly exceeds 4 lb/sq ft. Since this last condition is not the usual work condition, we have found it advisable to apply a factor of safety that should assure the ability of the machine to operate in this limiting condition.

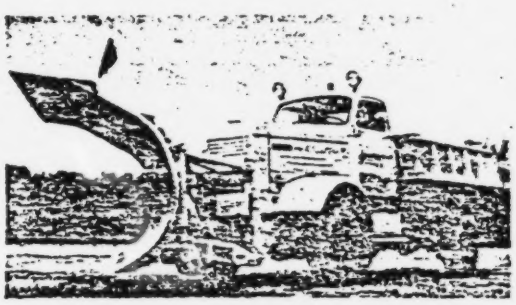


Fig 9 - Conventional blade type snow plow

As we said at the beginning of this paper, this machine should accomplish two distinct tasks:

1. Break up and displace the mass of snow.
2. Project this snow to an appreciable distance.

The calculations have shown that to project 40,000 lb/minute of snow, having a specific weight of 30 lb/cu ft and a resistance of 4 lb/sq in., a distance of 150 ft requires an output of 44.5 hp in the auger conveyors and 264 hp in the impeller, making a total power requirement for this machine of 308.5 hp.

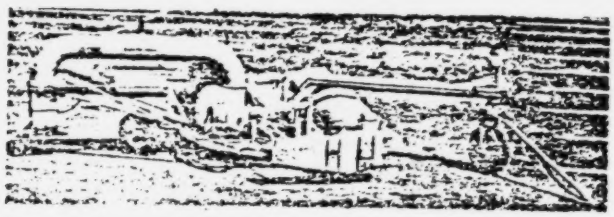


Fig. 10 - Sicard SW-112 airport sweeper

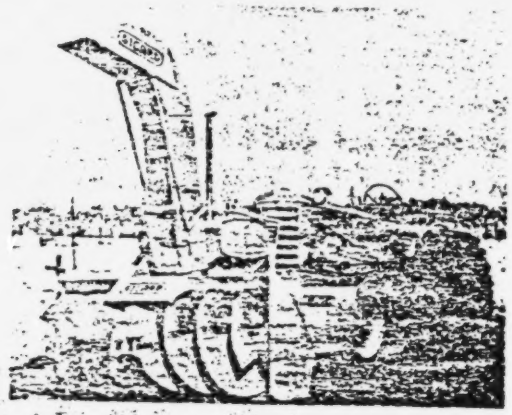


Fig. 11 - Sicard blower, Model BB

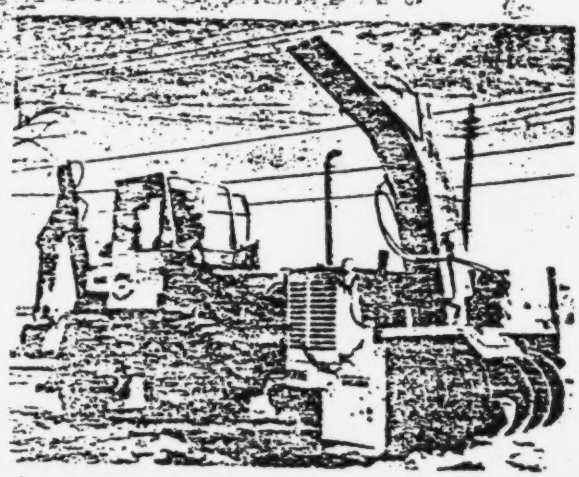


Fig. 12 - Single conveyor unit blower

MODEL APPLICATIONS OF COMPONENTS

The above calculations have been presented so that some insight into the manner of calculating the performance of blower-type snow plows may be gained. Photographs are included to show a typical reversible conventional blade-type snow plow (Fig. 9).

An airport sweeper of interesting design is also illustrated (Fig. 10). The broom may be angled 30 deg to either side, and a reversible nozzle is placed behind the broom, to blow a high velocity jet of air that removes small stones and like objects. This is the Sicard SW-112 sweeper.

Different configurations of blowers are included to show:

1. A self-contained small unit mounted on a tractor with integral impeller and conveyor screws on the same axis (Fig. 11, Sicard Model BB).

2. A similar unit, of higher capacity, mounted on a loader is shown in Fig. 12. This also has the impeller mounted on the single conveyor unit (Sicard Model BM).

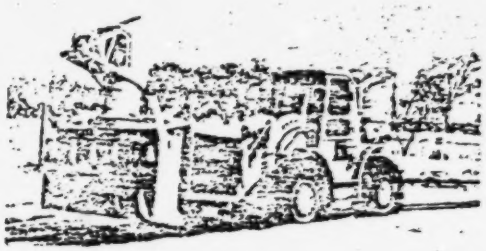


Fig. 13 - Two conveyors and one impeller (Sicard Model BK)

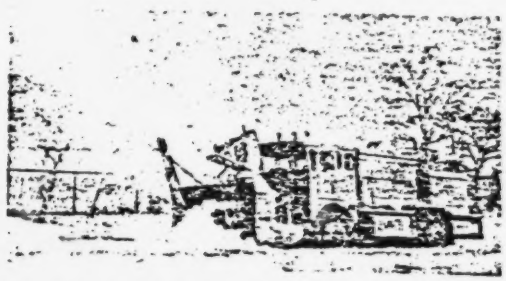


Fig. 14 - High speed airport service blower

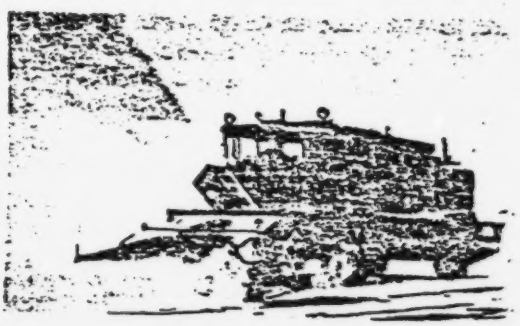


Fig. 15 - Conveyors replaced by a V plow

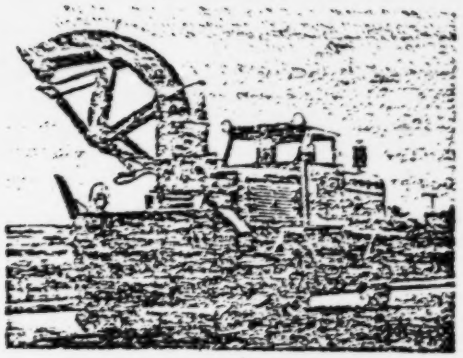


Fig. 16 - Street cleaning blowers

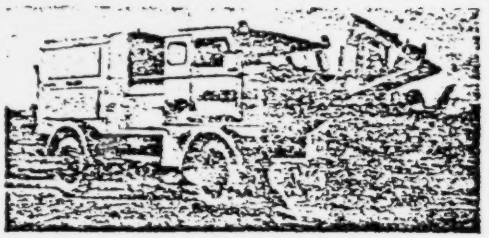


Fig. 17 - Chassis mounted power units

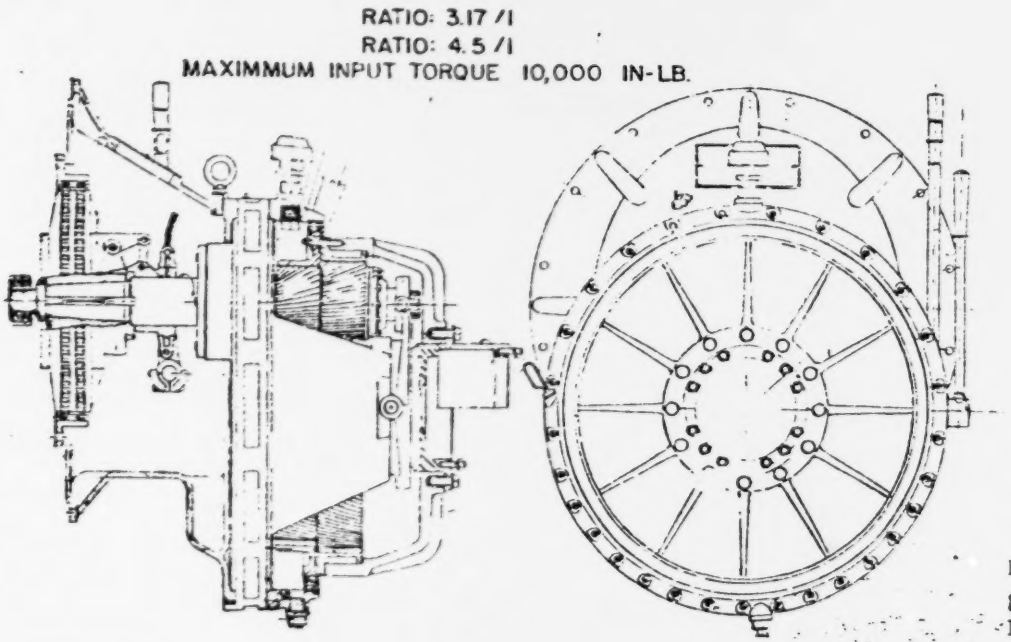


Fig. 18 - Two speed gear box assembly, Model BL snow blower

These units have swivelling chutes and the top may be adjusted hydraulically for loading or throwing.

3. A larger capacity unit, also self-contained, mounted on a Caterpillar loader is shown in Fig. 13. This unit has two conveyors placed one above the other, and a separate impeller (Sicard model BK).

4. Fig. 14 shows a somewhat similar conveyor impeller arrangement mounted on a special chassis for high speed airport service. Note that the power unit is now mounted on the chassis of the truck. (Sicard Model BX).

5. In Fig. 15 is a subsequent development of an airport unit in which the conveyors are replaced by a V plow behind which is placed a high capacity blower (Sicard model VX).

6. The Sicard "Junior" and "Snowmaster" models are seen in Figs. 16 and 17, respectively, having double conveyors, separate impellers, chutes for loading or blowing, and power units mounted on the chassis. These are principally used for major street cleaning operations.

7. A major feature of snow blower development is the necessity for design and development of special gear boxes to suit the application. A typical two speed box developed at Sicard is shown in Fig. 18.

REFERENCES

1. Karl Croce, "Measurements Relative to Performance and Efficiency of Snow Removal Machines for Highways," U. S. Army Corps of Engineers, Eng. Div., Berlin, 1950.

2. M. G. Bekker, "Snow Studies in Germany," Technical Memorandum No. 20, National Research Council of Canada.

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SNOWMASTER SNOWBLOWER CALCULATIONS

The same design procedure as used by Walker is used here. Where the author of this report deviates from Walker's method will be noted in the course of the calculation.

Data

(1) Quantity of snow for removal: 100,000 lbs/min

(2) Distance of cast: 75 ft

(3) Width of swept path: 10 ft (120")

(4) Mean height of snow bank: 4 ft (48")

(5) Physical characteristics of snow:
  (a) specific weight: 30 pcf
  (b) resistance of snow: 4 lbs/sq.in.

Calculations for vehicle speed

Section of snow facing machine: $4 \times 10 = 40$ sq. ft.

Output in cfm: $Q = \frac{100{,}000 \times \text{cu. ft}}{\text{minutes} \times 30 \text{ lb}} = 3{,}333$ cfm

Speed of vehicle:

$$V = Q/A$$

$$= \frac{3333}{40}$$

$$= 83.3 \text{ fpm}$$

Dimensions of conveyor

Discharge for each part of conveyor (four parts):

$$\frac{3333}{4} = 833.25 \text{ cfm} \quad (23{,}997.6 \text{ cu. in./sec.})$$

Assuming rpm of conveyor = 400,

$$\text{thickness of snow per revolution} = \frac{83.3}{400} \times 12 - 2.5"$$

Now the pitch of the conveyor is made equal to the radius R,

therefore: $$\frac{2\pi}{P} = \frac{2\pi \times N \times \pi(R^2 - (R-2.5)^2)}{60\ Q}$$

therefore: $$\frac{2\pi}{R} = \frac{2\pi \times N \times \pi(5R - 6.25)}{60\ Q}$$

therefore: $$\frac{1}{R} = \frac{5R - 6.25}{1145.8}$$

therefore: $$5R^2 - 6.25\ R - 1145.8 = 0$$

therefore: $$R = 15.78"$$

The previous calculation was made on the assumption that a circular annulus of snow forms in the conveyor. This is unrealistic, since if this were the case the annulus of snow would have to be stationary in the rotary sense, and have only axial velocity. The annulus would not support itself since centrifigual force would be zero. On the other hand, for the annulus to exist at all, it must rotate. If rotation speed were the same as the auger, there could be no axial movement and hence no axial discharge. The true state of affairs must be a condition between the two extremes. This means that axial movement must occur but not at the theoretical maximum determined by the product of pitch and conveyor revolutions. In order to achieve the output required, therefore, an annulus area larger than that predicted by the theory is required. To cater for this, the value of R (conveyor radius) just calculated has been arbitrarily increased to 20". This has the effect of adding approximately 30 per cent to the theoretical area.

Therefore: $R = 20"$ (i.e. $D = 40"$)

Now, since the pitch of the conveyor was made equal to the radius, R, it is possible to calculate the number of flutes per conveyor, i.e.:

$$N = L/P$$

Each conveyor is approximately 28" long. If the pitch is 20", then there will be 28/20 = 1.4 flutes per conveyor.

Analysis of forces acting on one flute of conveyor

Volume of snow per flute per cycle: 40 x 20 x 2.5 - 2,000 cu.ft.

Resistance of snow:

(a) force parallel to axis: $F_2 = 4 \times 40 \times 2.5 = 200$ lbf

(b) force in direction of travel: $F_1 = 4 \times 40 \times 20 = 3{,}200$ lbf

Value of normal component: $Fy = F_1 \sin \alpha + F_2 \cos \alpha$

where: $\alpha = \tan^{-1} \frac{P}{\pi D}$

$= \tan^{-1} \frac{20}{40\pi}$

$= 9.1°$

Therefore: $Fy = 3{,}200 \sin 9.1° + 200 \cos 9.1° = 704$ lbf

Force of friction

Assume coefficient of friction = $\mu = 0.08$.

Therefore: $F_f = 0.08 \times 704 = 56$ lbf/flute

Therefore:

$$\text{friction torque} = F_f R = 56 \times 20 = 1{,}120 \text{ lbs.ins./flute}$$

Power required to overcome friction is calculated (note that this power requirement was ignored in Walker's paper):

$$HP_f = \frac{2\pi \times \text{rpm} \times T}{33{,}000}$$

$$= \frac{2\pi \times 400 \times 1120}{33{,}000 \times 12}$$

$$= 7.11 \text{ hp per flute}$$

Since there are 1.4 flutes per conveyor and there are four conveyors, the total power to overcome friction is equal to:

$$7.11 \times 1.4 \times 4 = 39.8 \text{ HP}$$

Power required to break up snow

Work to overcome force F_2 for one revolution:

$$T_1 = F_2 \times P$$

i.e. $T_1 = 200 \times 20 = 4{,}000$ lbs.ins./per flute.

Work to overcome F_1:

$$T_2 = F_1 \times H$$

i.e. $T_2 = 3{,}200 \times 2.5 = 8{,}000$ lbs.ins./per flute

Work T_1 is done by the conveyor drive and work T_2 is done by the vehicle itself. Therefore, power required by conveyor to break up snow is calculated as follows:

There are four conveyors having 1.4 flutes each.

Speed of conveyor is 400 rpm.

$$\text{Power} = \frac{4,000}{12} \times 4 \times 1.4 \times \frac{400}{33,000} = 22.63 \text{ hp}$$

Power required to displace snow

For one of the conveyors on the auger the rate of moving snow is 25,000 lb/min. Approximate length of each conveyor is 28". The following table gives the quantities of snow and the distances moved by the conveyor:

Quantity	Q lbs/min.	Distance (ins)
A	10,000	28
B	10,000	16.8
C	5,000	5.6

Using a material factor of 4, the horsepowers are calculated as follows:

$$\text{Quantity A: HP} = \frac{10,000 \times 28 \times 4}{33,000 \times 12} = 2.83$$

$$\text{Quantity B: HP} = \frac{10,000 \times 16.8 \times 4}{33,000 \times 12} \quad 1.7$$

$$\text{Quantity C: HP} = \frac{5,000 \times 5.6}{33,000 \times 12} = 0.28$$

Total for one conveyor = 4.81 hp

Adding a contingency of 1 hp to take care of possible submergence of conveyor due to collapse of snow front, the power required for one conveyor is 4.81 + 1 = 5.8 hp. Since there are four conveyors, the total power required to displace the snow is calculated as:

$$5.81 \times 4 = 23.24 \text{ hp}$$

The net power requirement for the auger is found by adding the power required to overcome friction, the power required to break up the snow, and the power required to displace the snow. Thus:

$$\text{Net power} = 39.8 + 22.63 + 23.24 = 85.7 \text{ hp}$$

$$\text{Total power} = \text{net power} \times \text{service factor}$$

$$= 85.7 \times 1.2$$

$$= 102.8 \text{ hp}$$

The impeller

Casting distance = 75 ft

Rpm = 450 approx.

Useful power of auger to displace snow is:

$$4.81/4 = 1.2 \text{ hp}$$

Therefore, speed of entry to impeller is calculated from the following formula:

$$HP = \frac{W (V_f^2 - V_i^2)}{2 \times g \times 550}$$

i.e.
$$1.2 = \frac{25{,}000 (V_f^2 - 1.388^2)}{2 \times 32.2 \times 550 \times 60}$$

therefore:
$$V_f = \sqrt{\frac{1.2 \times 2 \times 32.2 \times 60 \times 550}{25{,}000}} + 1.93$$

$$= 31.97 \text{ fps (say 32 fps)}$$

Speed of exit from impeller is calculated from the relationship:

$$\text{Distance} = \frac{V^2 K^2 \sin 2\theta}{g}$$

where: K = air resistance factor = 0.7

V = exist velocity in fps

θ = angle of discharge

g = gravitational constant

Therefore:
$$V = \frac{\sqrt{75 \times 32.2/\sin 120}}{0.7}$$

$$= 75.4 \text{ fps.}$$

Therefore: required impeller diameter $= \frac{75.4 \times 60 \times 12}{\pi \times 450} = 38.4"$

Assume six blades. Therfore minimum angle of opening of discharge = 360/6 = 60°.

$$\cosh \beta = \frac{R}{r_o} = \frac{1}{C}$$

$$R = \frac{D}{2} \quad \frac{38.4}{2} = 19.2$$

$$\cosh \beta = \cosh 60° = 1.60379$$

Therefore: $\frac{1}{C} = 0.624$

Therefore: $r_o = 0.624 \times 19.2 = 11.99$ (say 12")

Width of impeller

Using Walker's suggested degree of compaction and loss due to friction in the impeller, the width of the impeller is calculated from the relationship:

$$S = 60 \times N \times F \times T \times 0.75$$

Therefore: $$T = \frac{S}{60 \times N \times F \times T \times 0.75}$$

There are two impellers and the volume per impeller, assuming a specific weight of 45 lbs/cu.ft. in the impellers, is calculated as:

$$\frac{6,000,000}{2 \times 45} = 66,667 \text{ cu.ft./hour}$$

Therefore: $$T = \frac{66,667 \times 144}{60 \times 450 \times \pi (19.2^2 - 12^2) \times 0.75} = 8.06"$$

If the impeller is made 10" wide there will be available an overcapacity equal to approximately 3,700 tons/hour available at the blowers. This will take care of any incidence of surging.

Horsepower absorbed by snow in turbines

$$hp = \frac{W \times (V_f^2 - V_i^2)}{2 \times g \times 60 \times 550}$$

$$= \frac{50,000 \ (75.4^2 - 32^2)}{2 \times 32.2 \times 60 \times 550}$$

$$= 109.7 \text{ per turbine.}$$

Allowing 30 per cent losses in turbine power, input to turbine becomes:

$$\frac{109.7}{0.7} = 156 \text{ hp}$$

Therefore, total power required by auger and blowers is:

$$102.8 + (2 \times 156) = 414.8$$

Mechanical efficiency = 0.82. Therefore, required engine power is:

$$\frac{414.8}{0.82} = 507 \text{ hp}$$

APPENDIX C

SPECIFICATIONS OF SNOWMASTER

Length:	with snowblower deployed	74'8"
	with snowblower parked	69'0"
Weight:		70 tons (approx.)
Snowblower capacity:		3000 tons/hour
Casting distance:		75 feet
Maximum speed while plowing		60 mph
Maximum speed under own power		5 mph
On-board power:	snowblower, diesel engine	650 hp
	self-propulsion, diesel engine	150 hp
Accommodation:		5 crew members
	Facilities include dining, kitchen, closet and washroom	
Features:	Variable plowing geometry, deployable snowblower, flanger, reversing turntable, side wings, locomotive-type control cabin with remote control for locomotive.	

APPENDIX D

DISCUSSION OF PRELIMINARY DESIGNS

The development of the finally accepted design concept was the outcome of a prolonged period of "cut and try" design procedures and a series of steering committee meetings. A number of preliminary designs were rejected for one reason or another. However, a significant amount of work was done to produce the preliminary design drawings and it was deemed to be imprudent to scrap these since some of the ideas and arrangements may possibly be of use at some later date. Also, because of the amount of work involved, it was considered important to present a brief discussion of the preliminary designs, giving reasons for their rejection.

Preliminary design drawings are presented in Appendix E. They are distinguished from the final design drawings by the use of the letter P (for preliminary) following the drawing number.

Drawing No. 1P, Rev. 0, shows the first arrangement which was considered. This was a six-axle vehicle consisting of a four-axle flatbed trolley supporting the turntable mount for the main body of the snowplow. The plowing surfaces at the front of the rotating upper section were supported on a two-axle truck located immediately beneath the elevation wedge.

The variable geometry plowing surfaces were of similar design to that chosen and described in the text. With the exception of the non-articulated deploying arms and the parking position, the design of the blower system was also the same as that finally chosen.

The arrangement of the flatbed and snowplow support truck essentially provided an articulated vehicle and it should be noted that the turntable was mounted on a gimble (see Drawing No. 2P, Rev. 0) which, together with the turntable itself, provided for vertical as well as horizontal articulation between the flatbed and the snowplow body proper.

The design was rejected for a number of reasons:

(1) It was considered undesirable to have an articulated vehicle design because of the danger of jacknifing while operating with a locomotive.

(2) The need to provide sustaining load on the snowplow truck during snowplowing operations and balancing of the main body of the snowplow for rotation of the upper section required the provision of heavy and bulky movable ballast in the body of the vehicle. It was felt that the mechanism to provide this would cause too much complication in the system.

(3) The parking position of the snowblower made it impossible to provide an access passage to the locomotive from the snowplow without having to descend to the ground. This violated one of the requirements of the operating requirements.

(4) The position of the blower deploying arms when parked caused an obstruction to adequate rearward side vision from the control cabin. The latter is mandatory in any locomotive-type control cabin.

(5) There was no provision for a switch broom.

The modified arrangement shown on Drawing 1P, Rev. 1, was an attempt to eliminate objections (3) and (5) as prelude to a complete redesign of the system.

Drawing No. 1P, Rev. 2, shows a further development designed to eliminate the other objections. In the latter design the body of the snowplow is again mounted on a two-truck flatbed. While plowing, the weight of the body is supported on the trucks so that there is no need for movable ballast and the rotating part may be balanced at the centre of the turntable. Before rotating, the whole upper body of the plow is lifted off the supporting trucks by means of a hydraulic ram turntable and is balanced so that rotation for plowing in the reverse direction is possible. When reaching the reversed position, the body is again lowered onto the trucks, so relieving the turntable.

While the latter design overcame most objections, the requirement for rearward vision was still thwarted by the position of the snowblower deploying arms and the design was rejected on this basis.

While deployment of the snowblower in the manner shown in these preliminary designs was deemed possible, there was a school of thought which advocated placement of the snowblower under the elevation wedge. It was the intention that the blower could be brought into service by raising a movable part of the wedge.

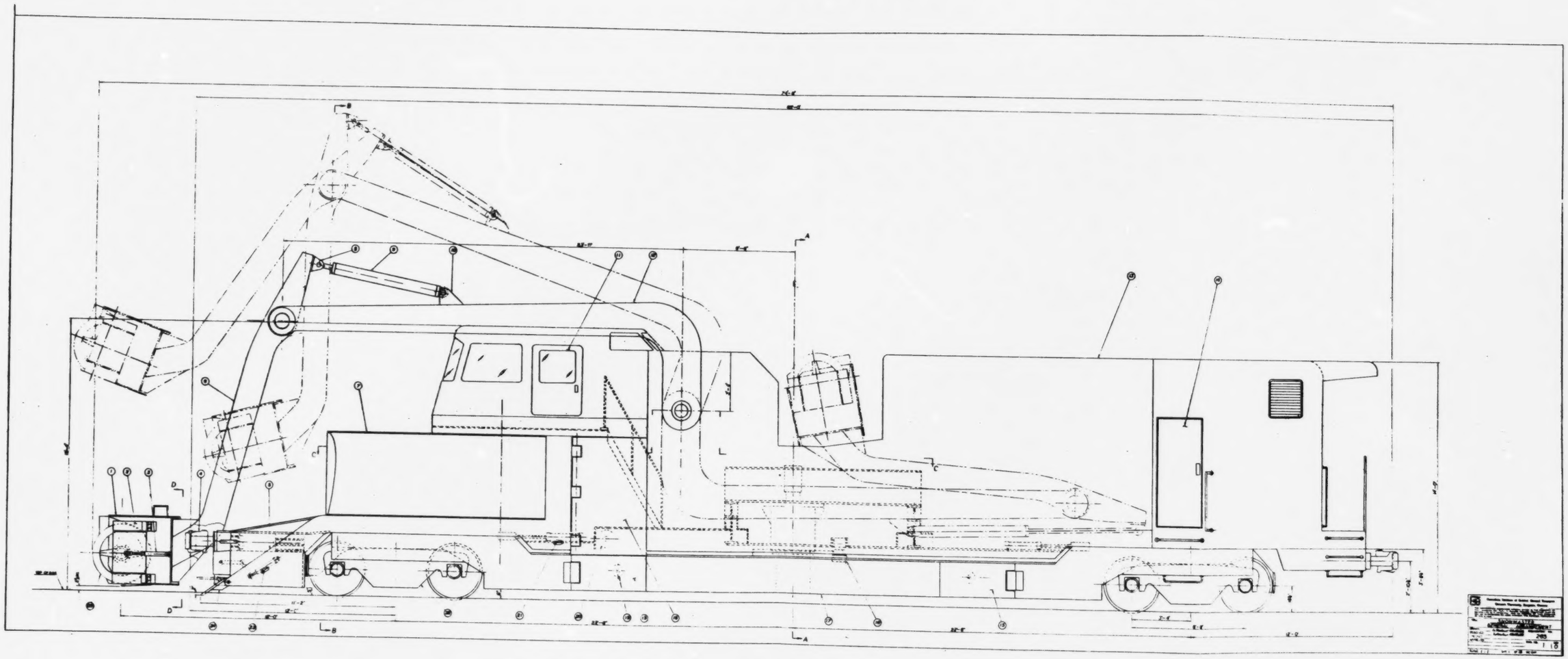
In an effort to comply with this suggestion, the arrangement shown on Drawing 1P, Rev. 3, was drawn up using practical design parameters. It was rejected for several reasons. First, it was decided that the overhang of 18'10" from centre of truck to leading edge of the elevation wedge was too great for efficient plowing. Second, the two alternative possible positions shown for the lifting section of the wedge gave problems in providing adequate forward vision from the control cab and/or providing the capability of orienting the blower casings for discharge all to the right, left or half each side.

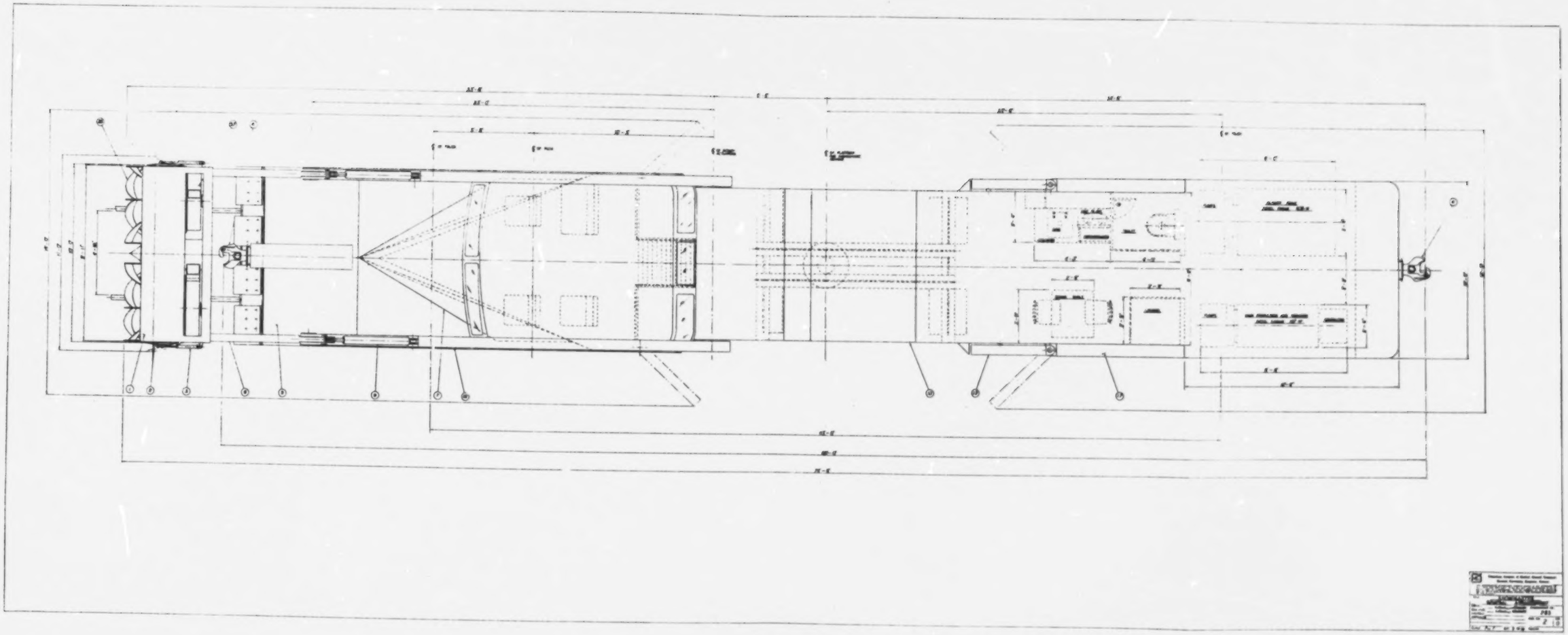
In general, the engineering problems and complications associated with location of the blower under the elevation wedge, while in principle not insurmountable, were deemed to be too great.

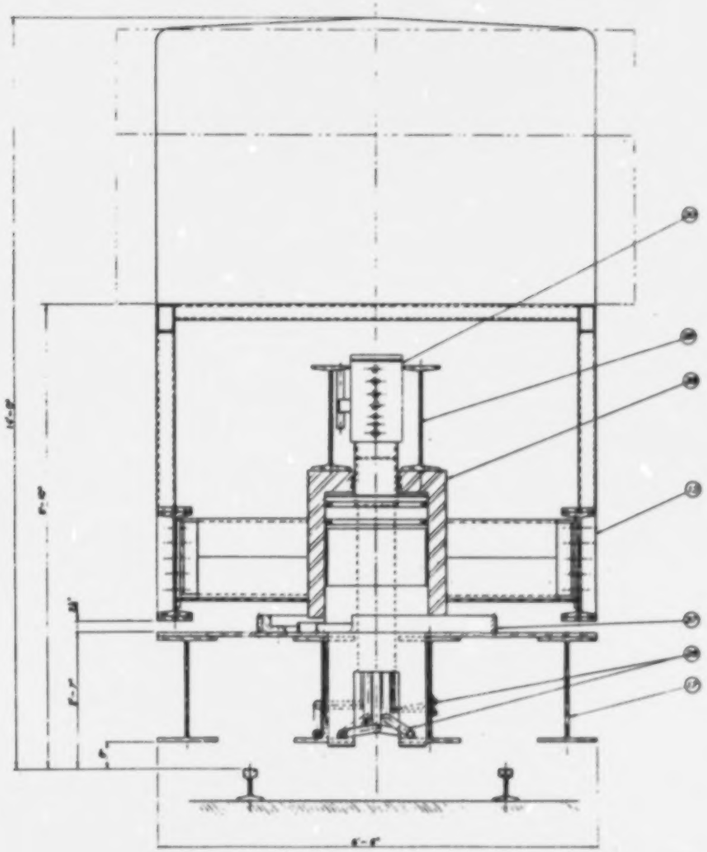
Preliminary drawings No. 3P and 4P show the initial layout drawings for the auger and auger drive for the snowblower. The pitch of the auger was later changed but the method of construction would be the same.

APPENDIX E

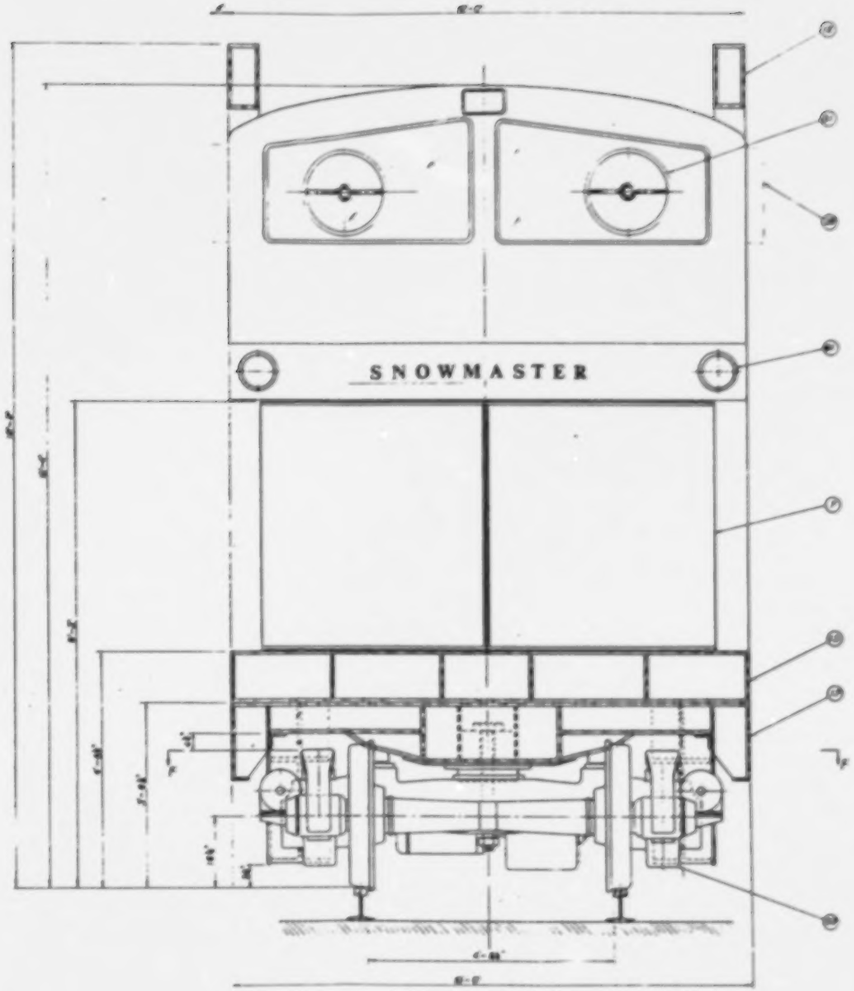
DRAWINGS







SECTION A-A



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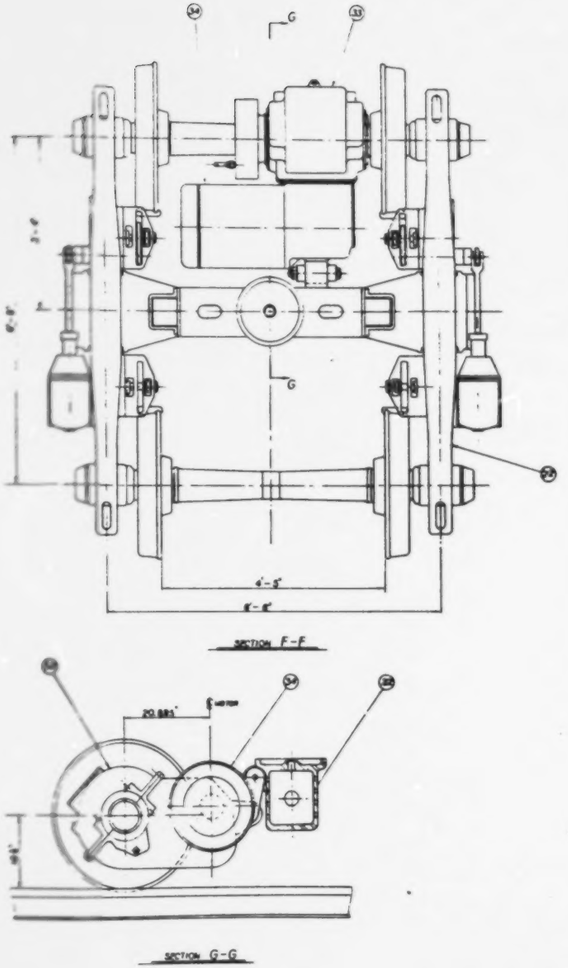

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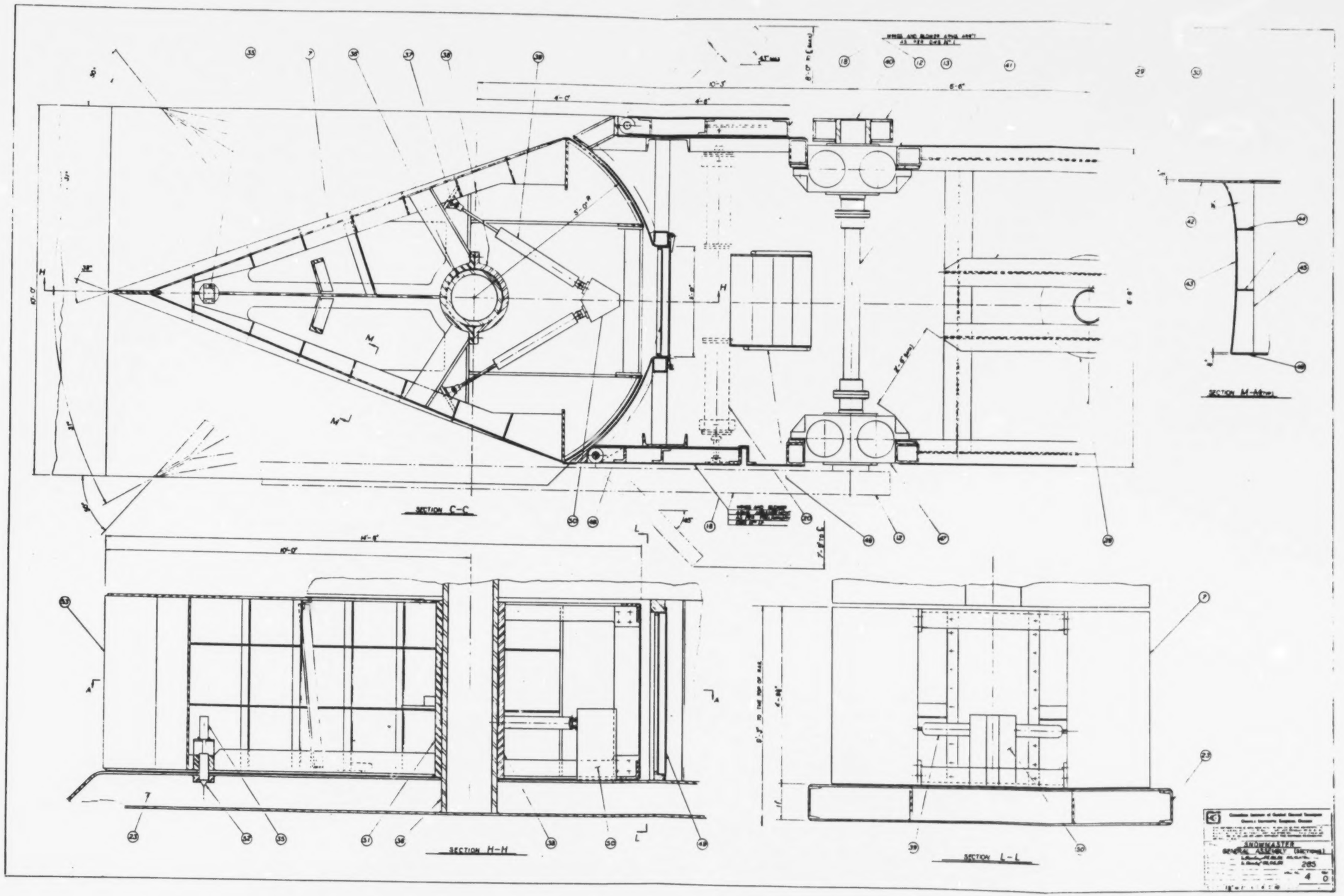
SECTION G-G

SNOWMASTER
GENERAL ASSEMBLY (SECTIONS)
265
3 OF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SECTION M-M
SECTION H-H
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GENERAL ASSEMBLY (SECTIONS)
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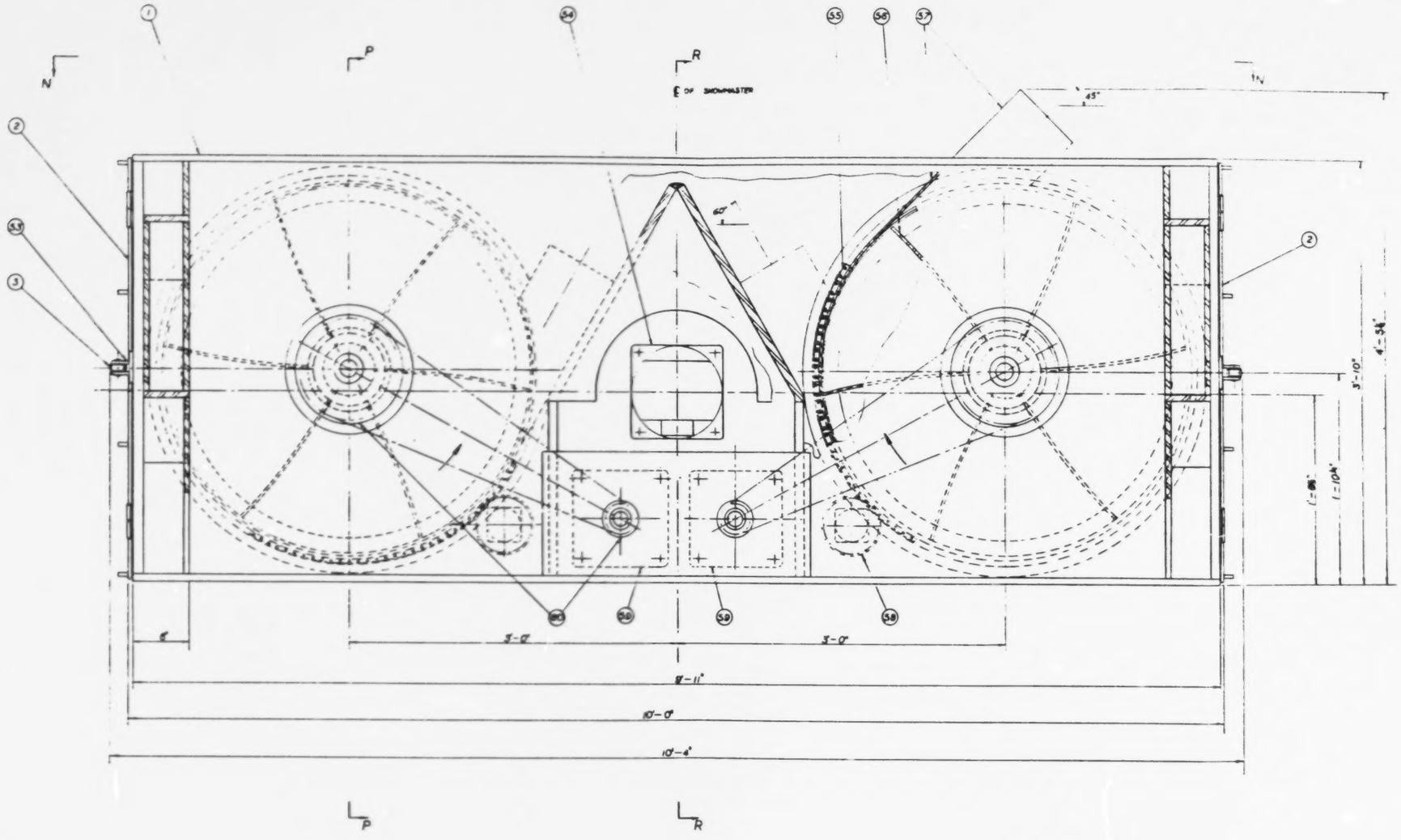

SECTION D-D

	SNOWMASTER
	GENERAL ASSEMBLY SNOW BLOWER
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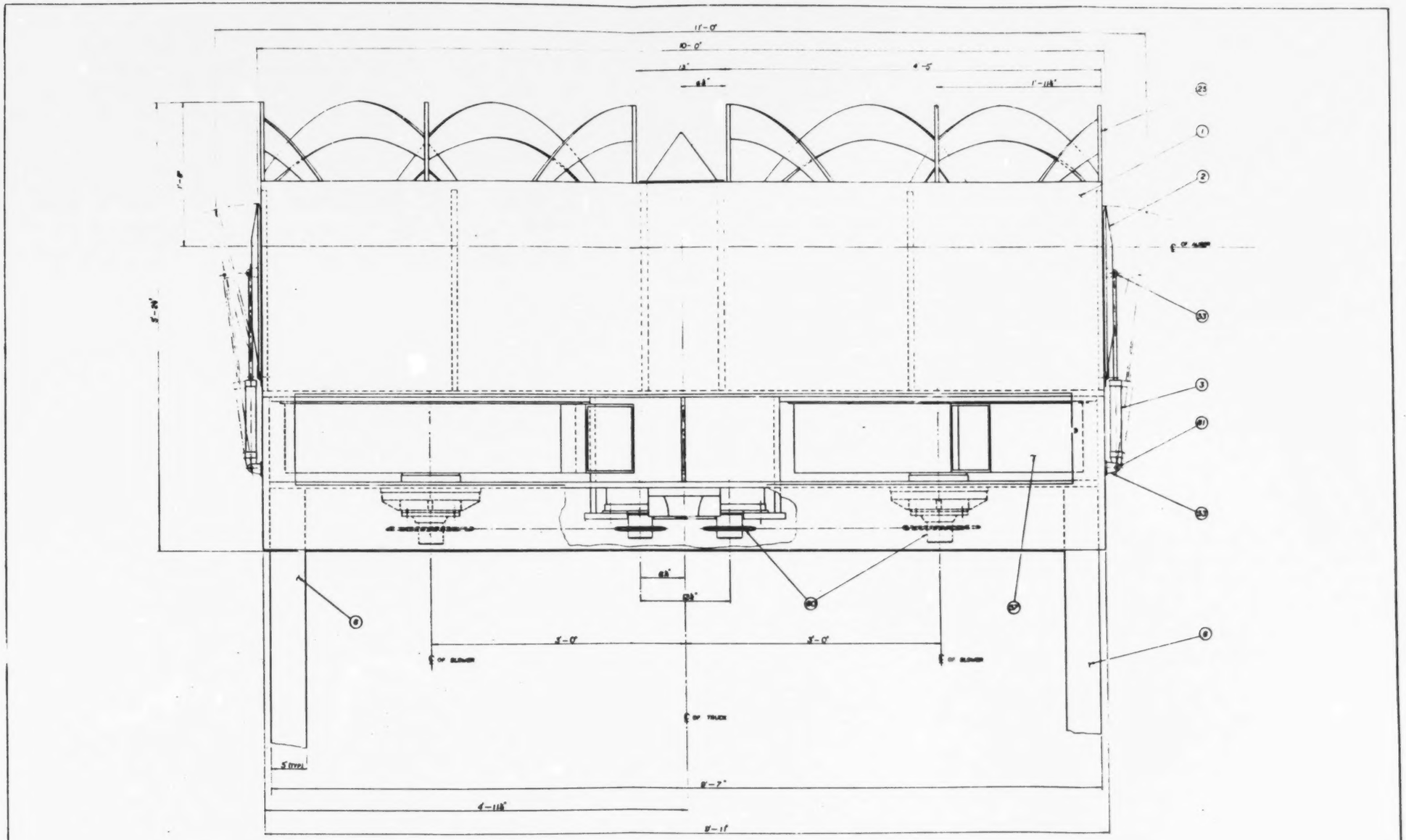
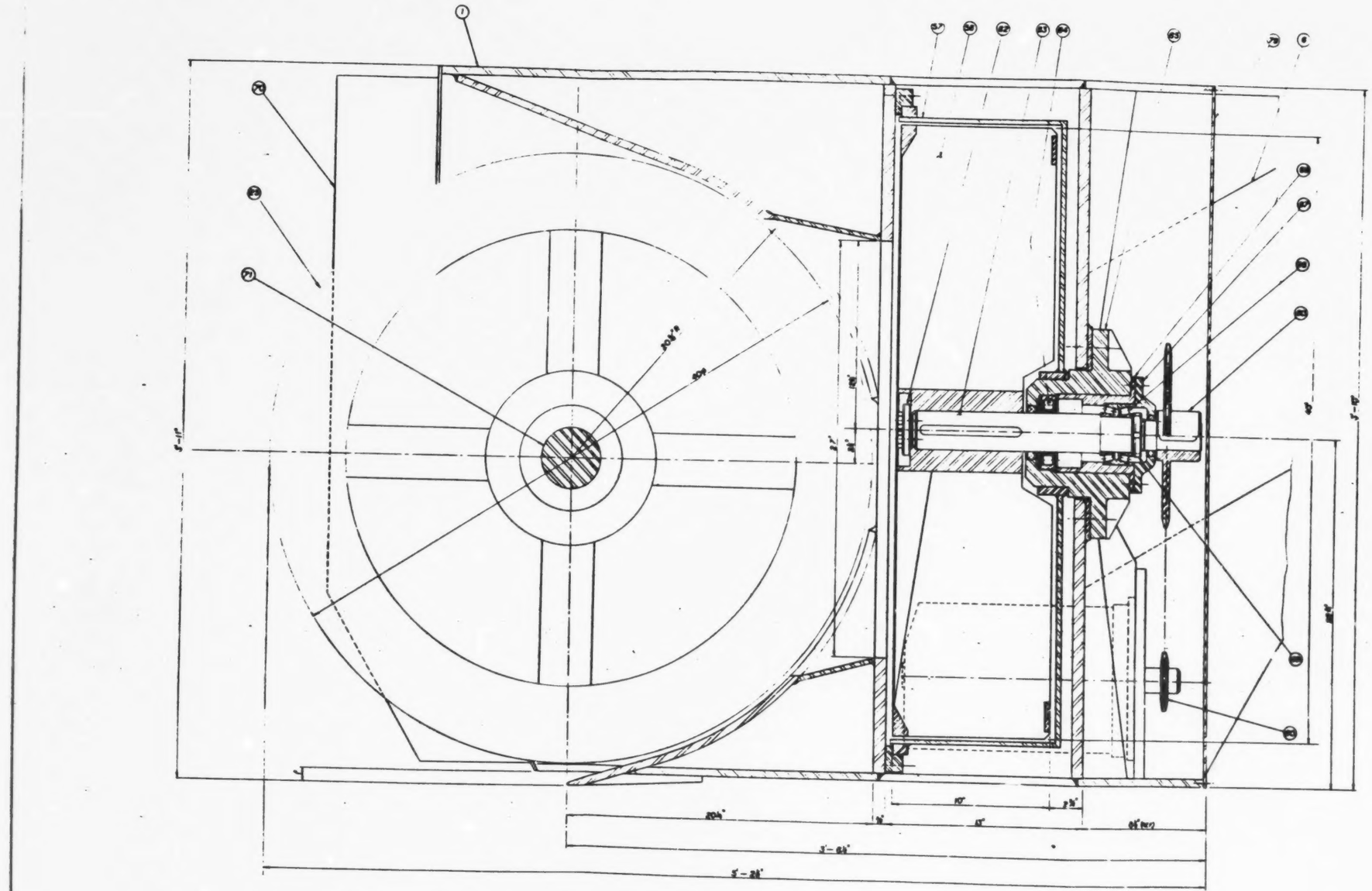
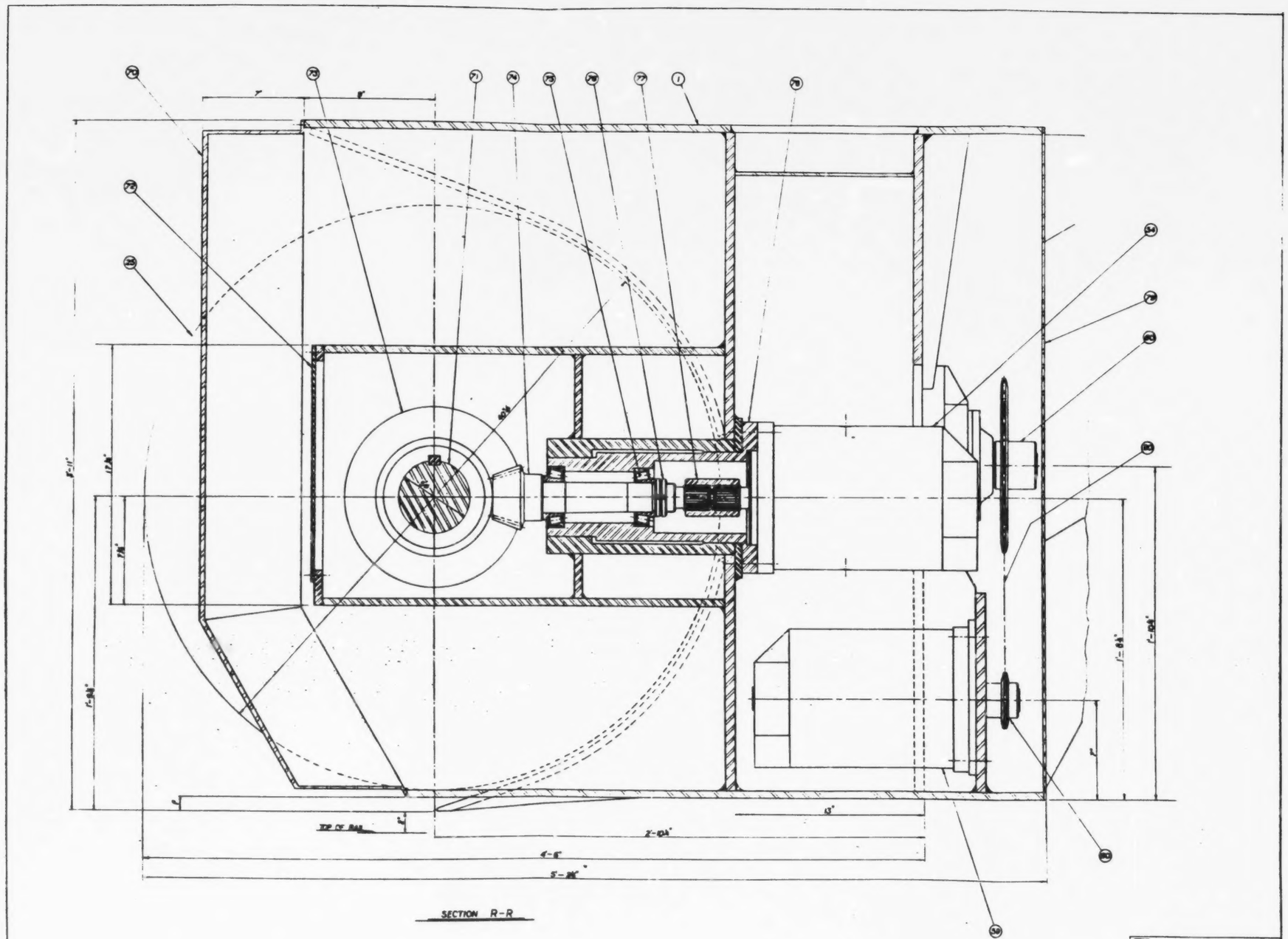


VIEW N-N

SNOWMASTER
ASSEMBLY SNOW BLOWER
263
6 10

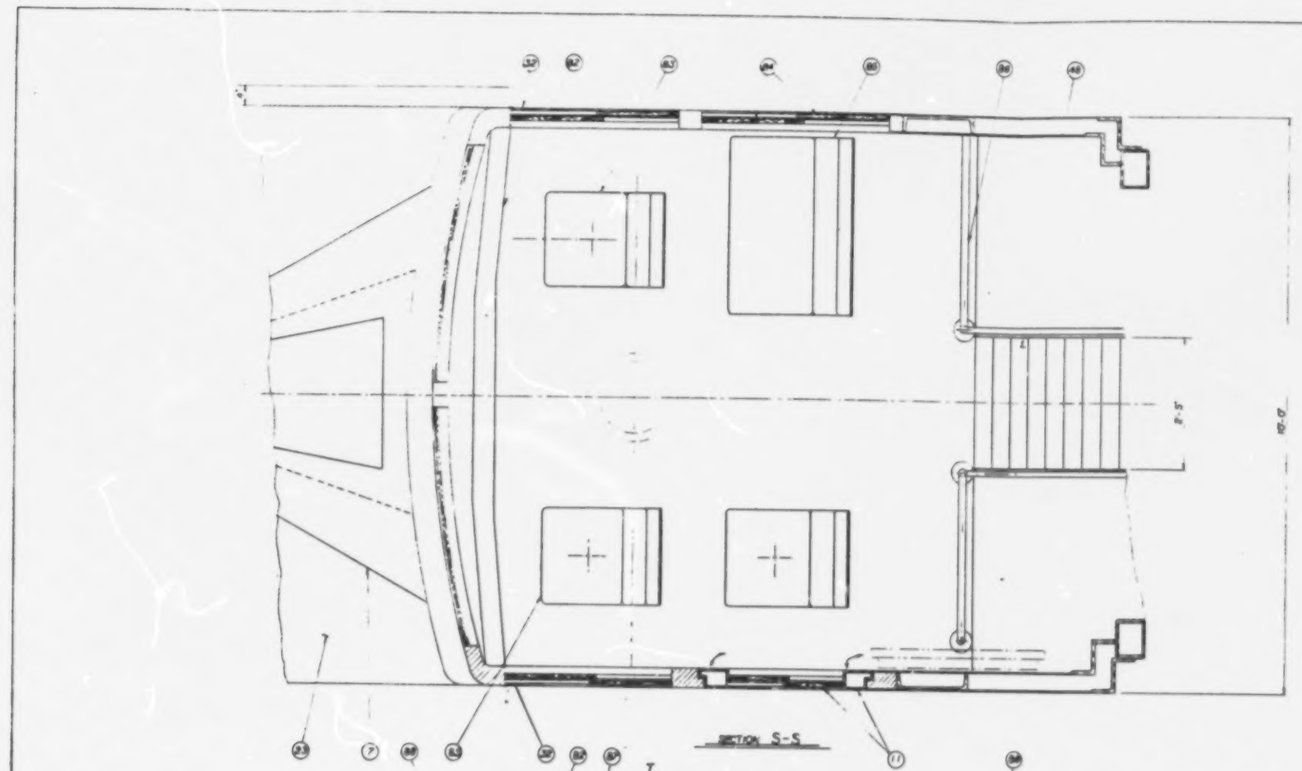


SECTION P-P



SECTION R-R

SNOWMASTER
GENERAL ASSEMBLY SNOW BLOWER
265
8



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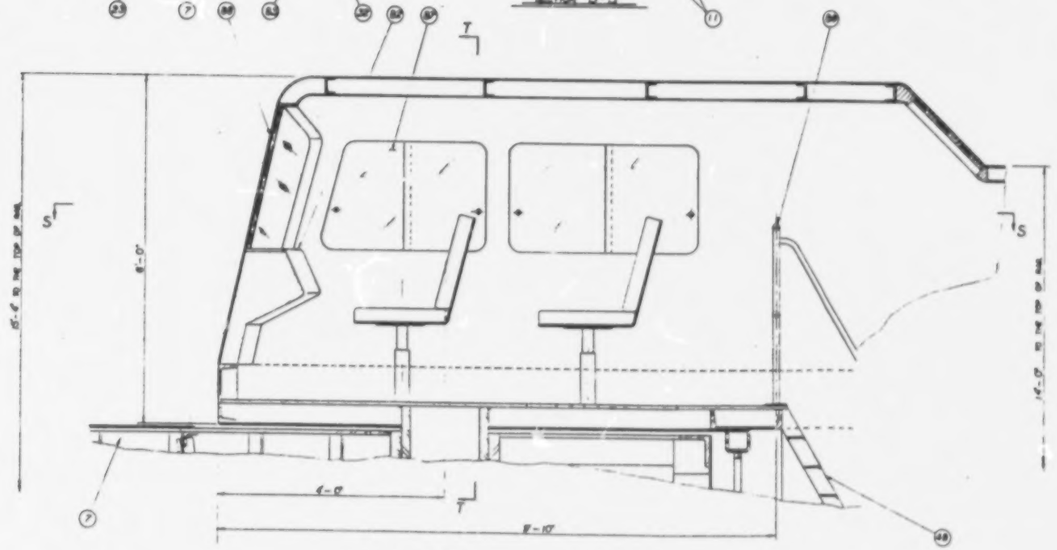

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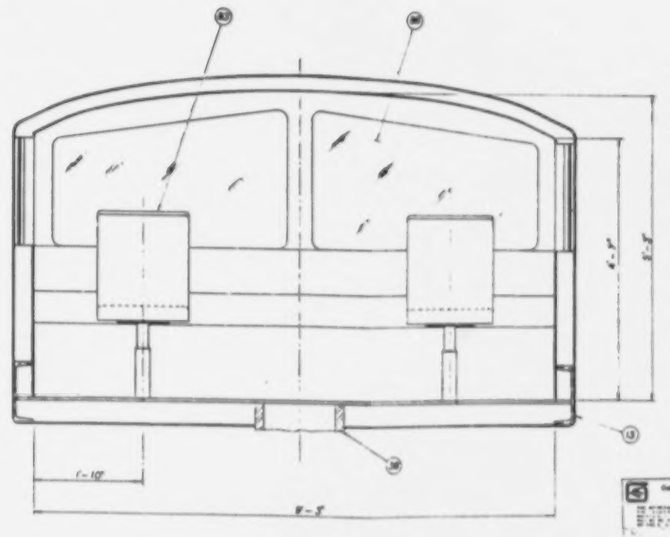

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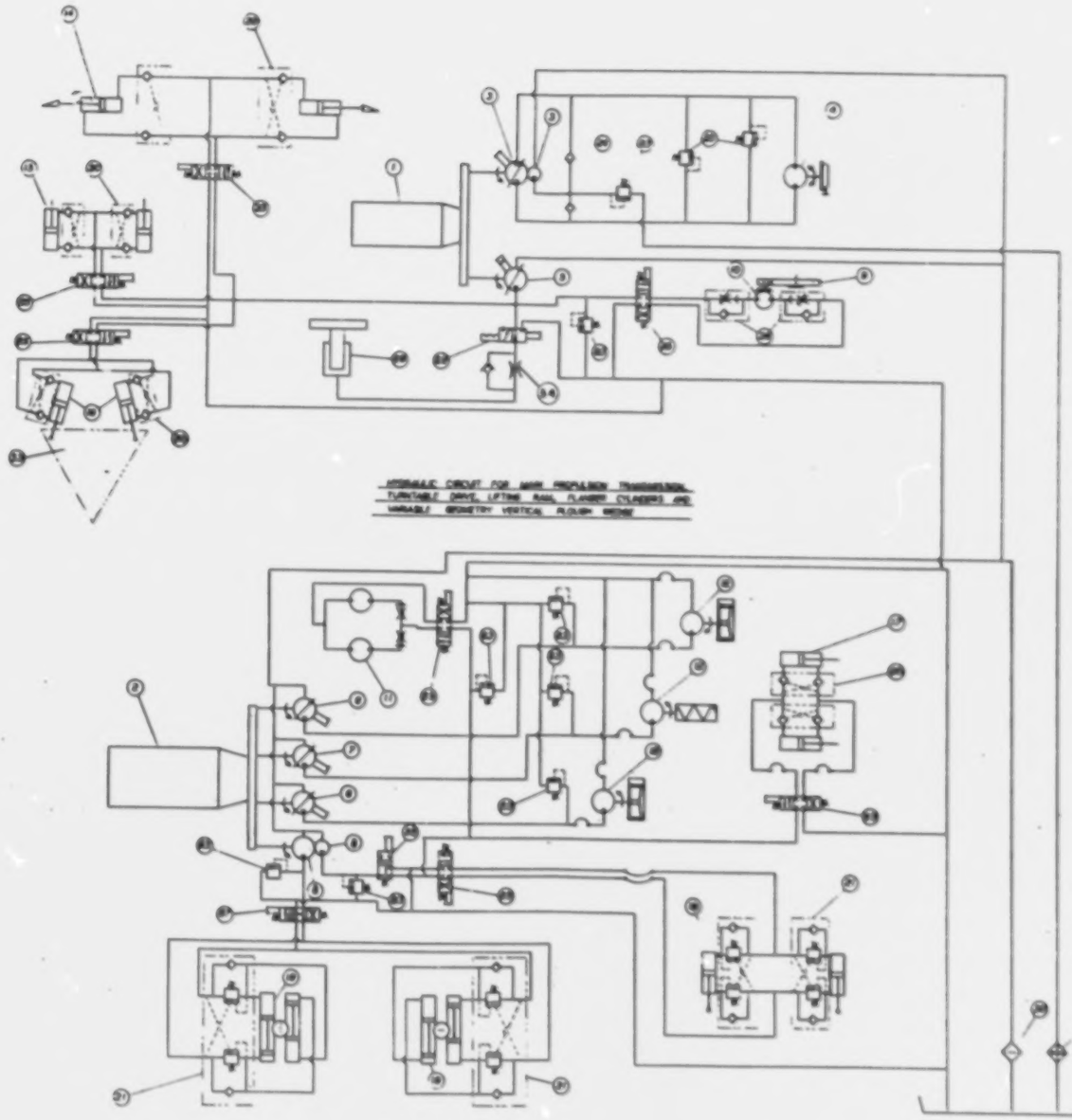
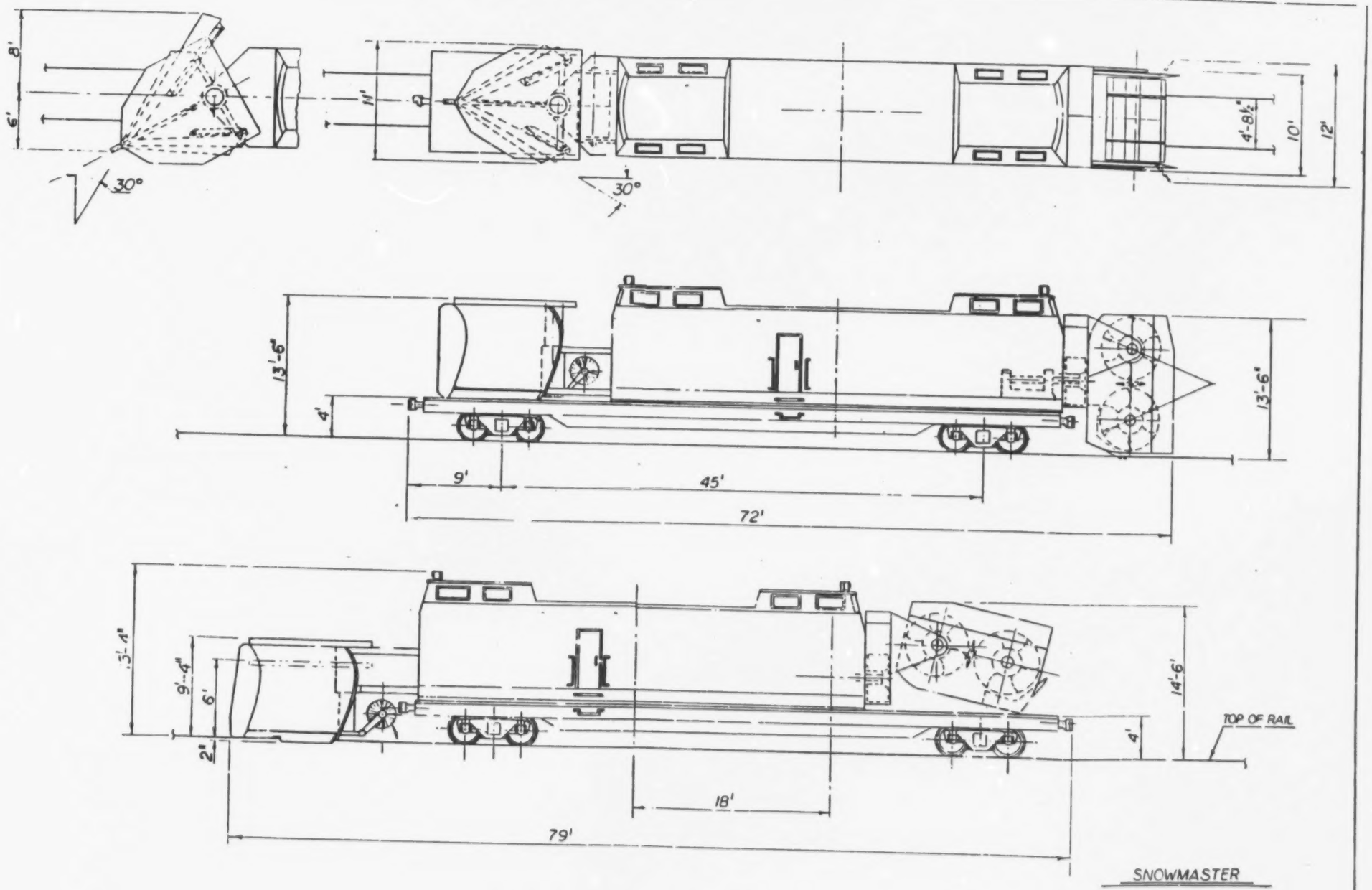

HYDRAULIC CIRCUIT FOR MAIN PROPULSION TRANSMISSION, TURNTABLE DRIVE, LIFTING RAIL, FLANGER CYLINDERS AND VARIABLE GEOMETRY VERTICAL PLOUGH WINGS
HYDRAULIC CIRCUIT FOR BLOWER AND EXPLOSIVE ARMS

ITEM	DESCRIPTION	QTY	REFERENCE INFO AND SUGGESTED MAKES
1	DIESEL ENGINE 147 Hp	1	VOLVO TWIN ENGINE MARK [illegible] COMPLETE WITH PLATE DRIVE, 2 PUMP AND MOUNTING
2	DIESEL ENGINE 835 Hp	1	DETROIT DIESEL 6V-71 STYLE PLATE DRIVE AND 2 PUMP
3	MAIN PROPULSION PUMP L.H.R. AXIAL PUMP	1	SUNDSTRAND SERIES 20 VARIABLE CAPACITY AXIAL PISTON
4	MAIN PROPULSION MOTOR	1	SUNDSTRAND SERIES 20 FIXED DISPLACEMENT HYDRAULIC MOTOR
5	SERVICES DRIVE PUMP	1	SUNDSTRAND VARIABLE CAPACITY AXIAL PISTON PUMP
6	BLOWER DRIVE PUMP	2	[illegible] VARIABLE CAPACITY [illegible] AXIAL PISTON PUMP
7	AUGER DRIVE PUMP	1	[illegible] VARIABLE CAPACITY [illegible] AXIAL PISTON PUMP
8	BLOWER WING AND BLOWER DEFLECTOR ARM PUMP	1	VICKERS GEROLE PUMP
9	TURNTABLE	1	
10	TURNTABLE DRIVE MOTOR	1	GEAR-LUNE 8545 SP.B FIXED CAPACITY
11	BLOWER CHUTE DRIVE MOTOR	2	
12	BLOWER DRIVE MOTOR	2	GEAR FIXED CAPACITY [illegible] AXIAL PISTON MOTOR
13	AUGER DRIVE MOTOR	1	GEAR FIXED CAPACITY [illegible] AXIAL PISTON MOTOR
14	TURNTABLE STEERING CYLINDER	2	
15	FLANGER CYLINDER	2	
16	SWING CYLINDER	2	
17	BLOWER WING CYLINDER	2	
18	EXPLOSIVE ARM ELEVATION CYLINDER	2	
19	HYDRAULIC REMOTE ACTUATOR	2	SAME DESCRIPTION AS USED ON AXIAL PISTON CONTROL UNIT
20	CROSS CHECK LOCKING VALVE	8	
21	MOTION CONTROL AND LOCK VALVE	4	
22	TWO WAY VALVE	1	
23	RELIEF VALVE	10	
24	CHECK VALVE	2	
25	FOUR WAY SPRING CENTERED HAND OPERATED VALVE	7	NORMALLY CLOSED
26	FLOW CONTROL VALVE	2	
27	FOUR WAY SPRING CENTERED HAND OPERATED VALVE	1	
28	TWO WAY VALVE	1	
29	LIFTING RAM	1	
30	FILTER	1	
31	COOLER	1	
32	OIL RESERVOIR	1	
33	SWING PLOUGH DEFLECTOR RAM	1	
34	ORIFICE BYPASS RESTRICTOR	1	

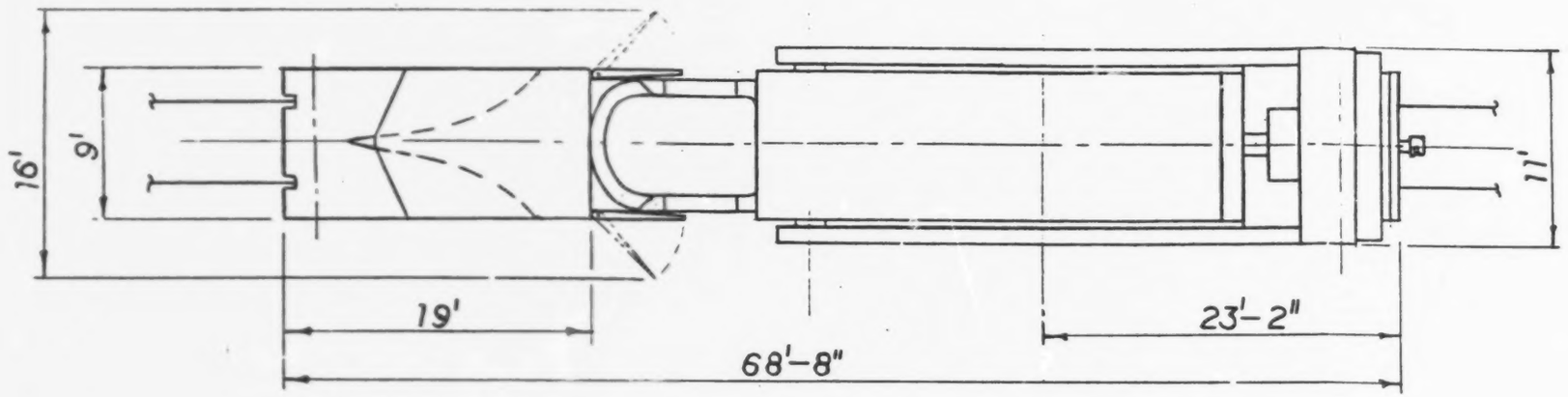
SNOWMASTER
BASIC HYDRAULIC CIRCUIT DIAGRAM

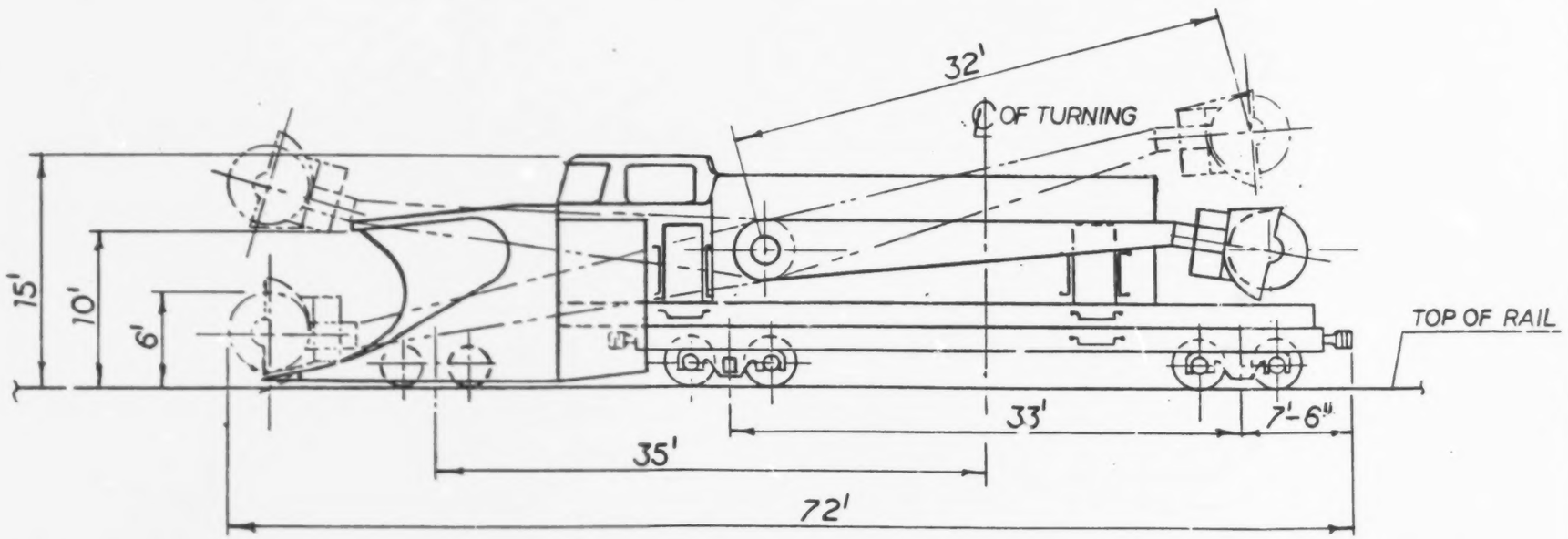
DWG. No. 10 0



DWG No 1P(a)

CIGGT





SNOWMASTER

DWG No IP (b)

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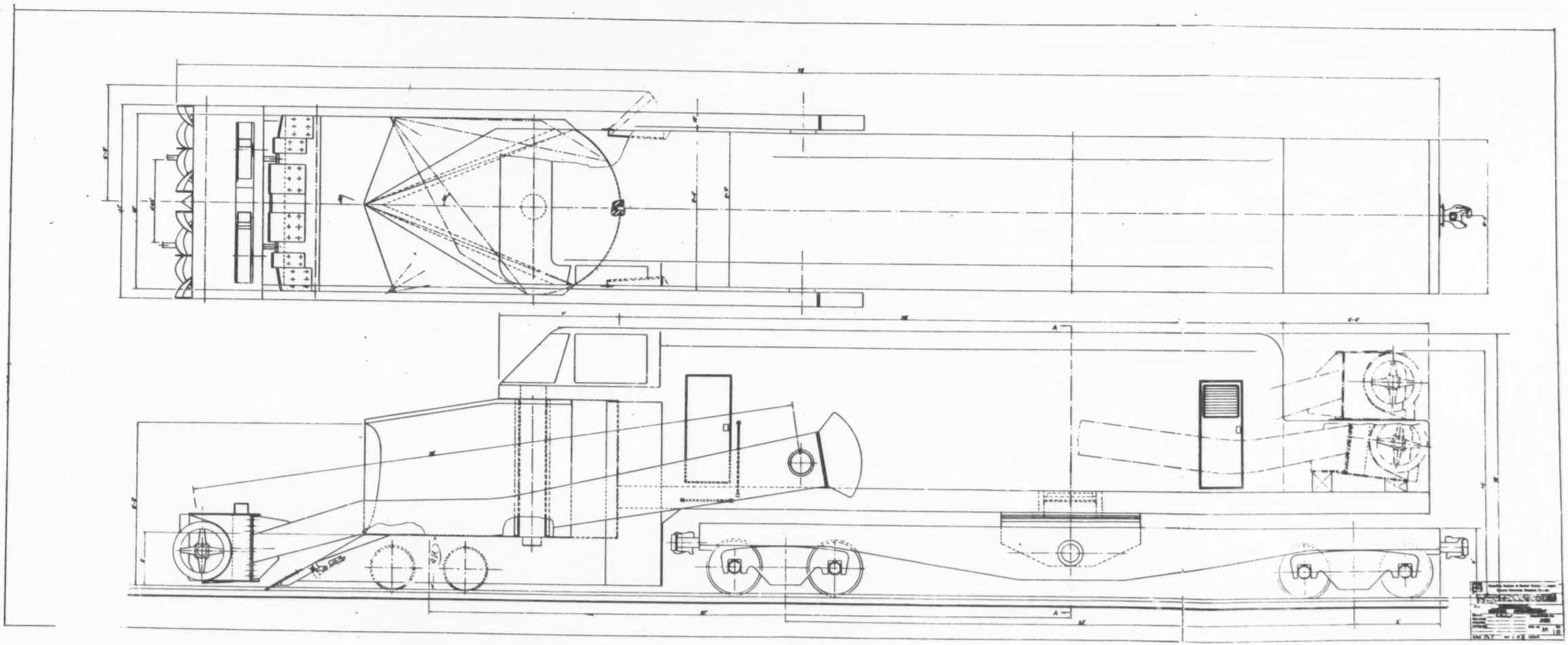
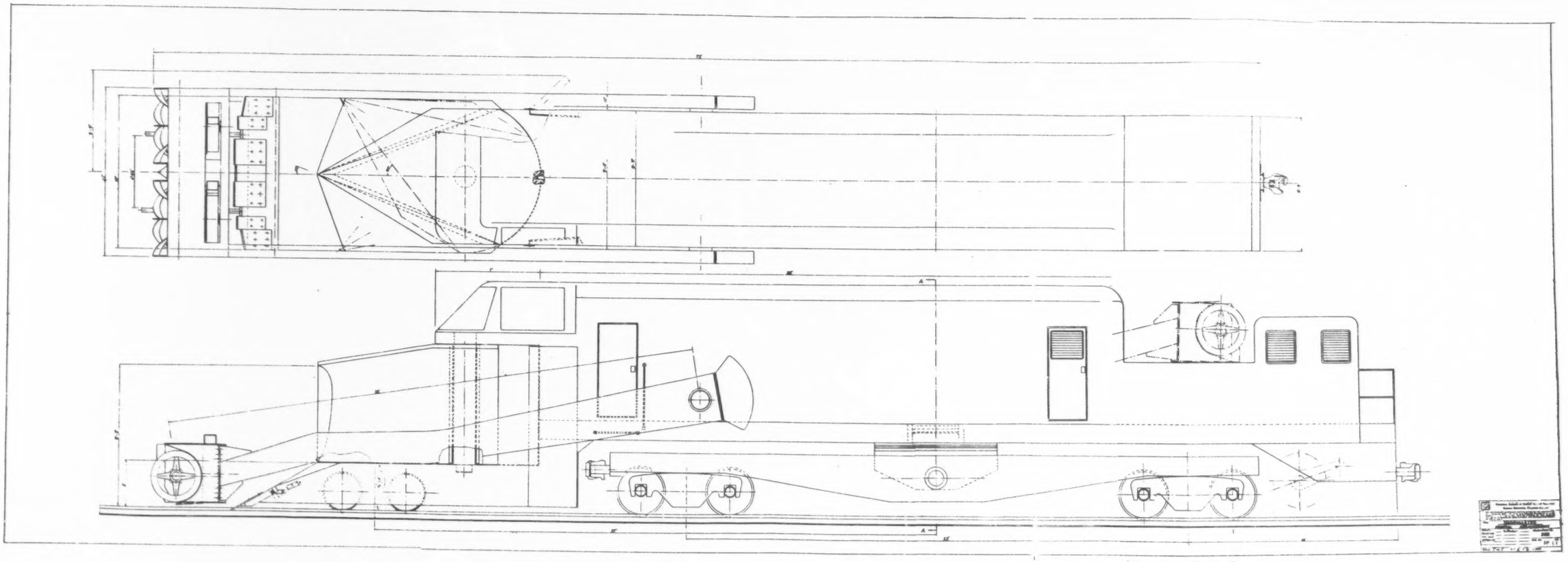
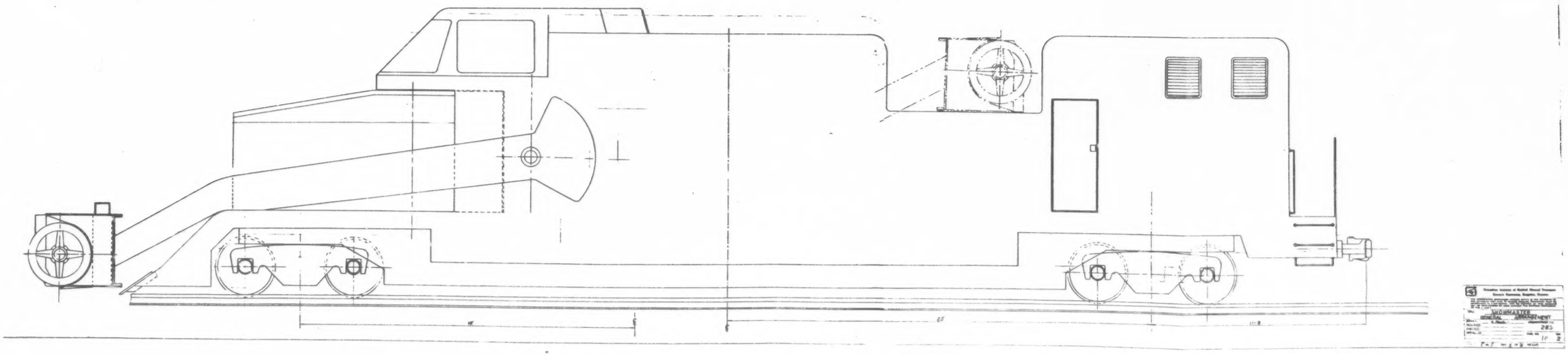
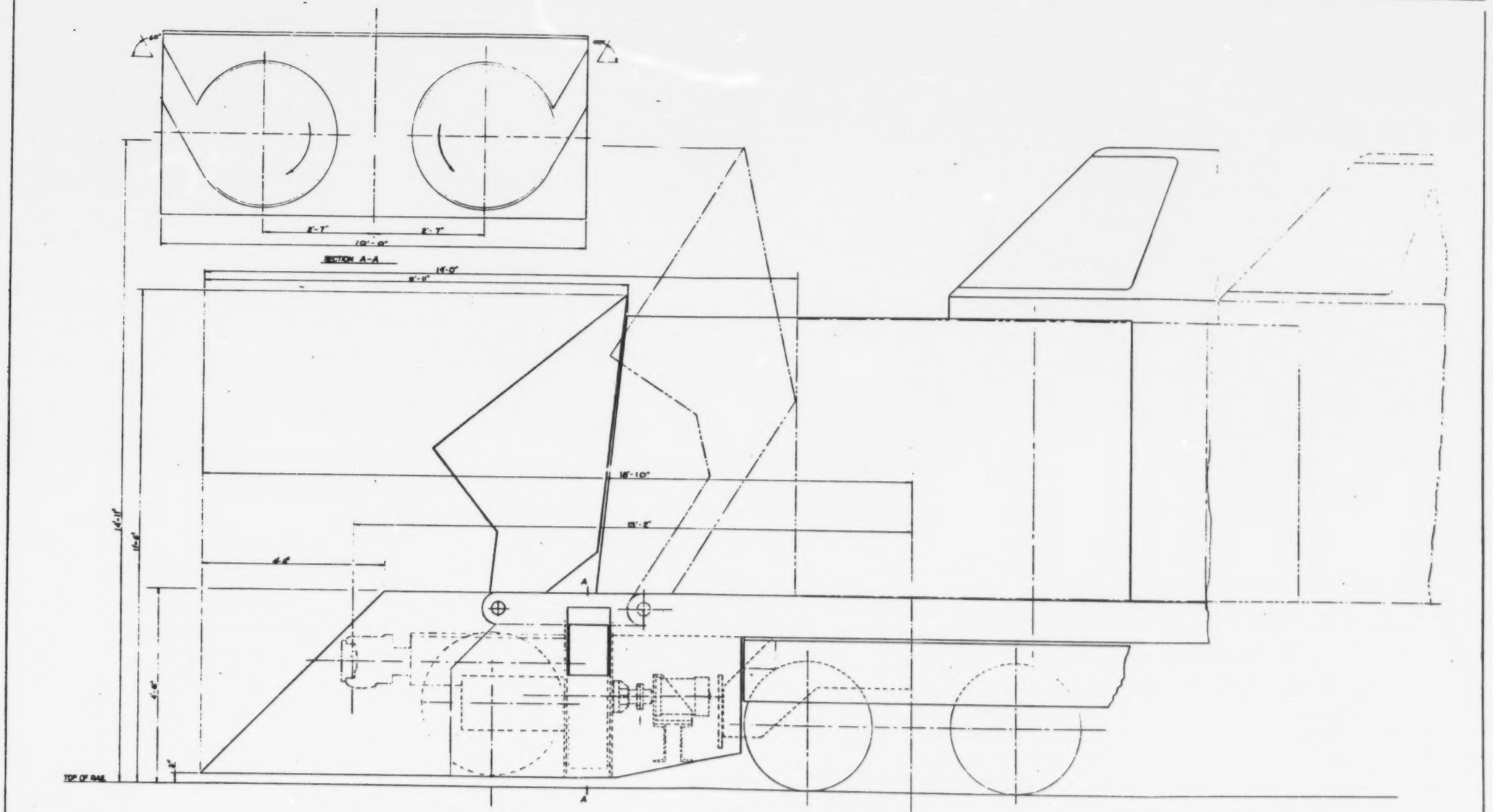
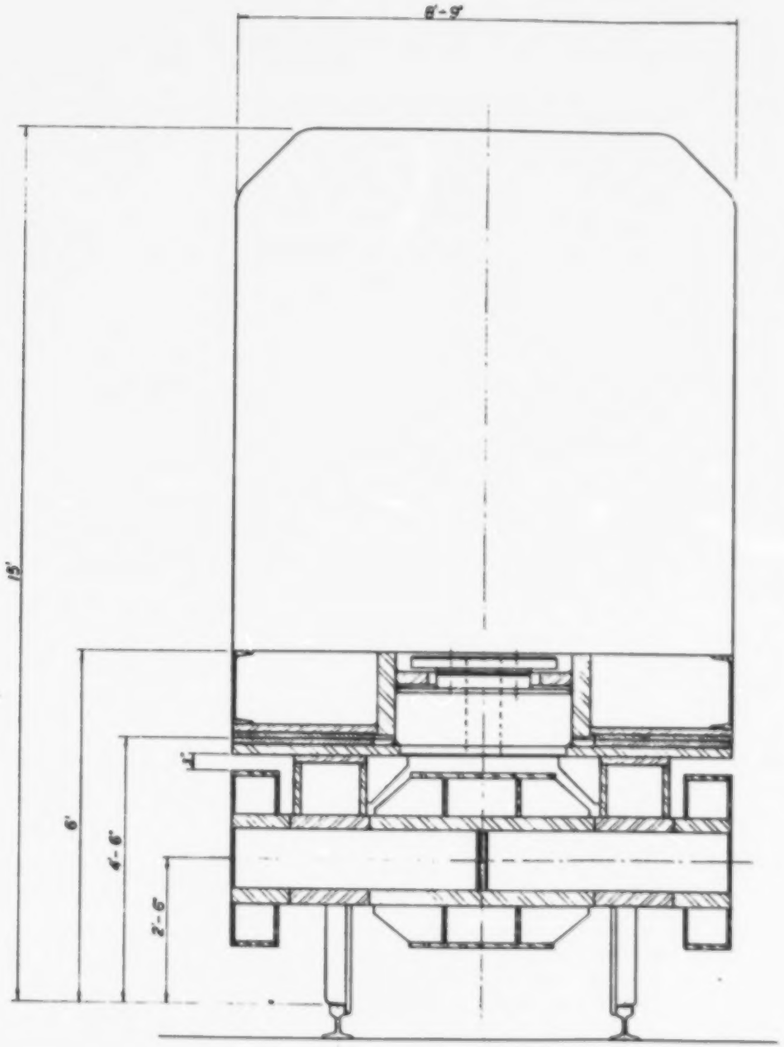







8'-7"
8'-7"
10'-0"
SECTION A-A
14-0"
8'-11"
16'-10"
15'-2"
14'-11"
15'-8"
4'-6"
TOP OF RAIL



SECTION A-A

Canadian Institute of Guided Ground Transport
Queen's University Kingston, Ontario

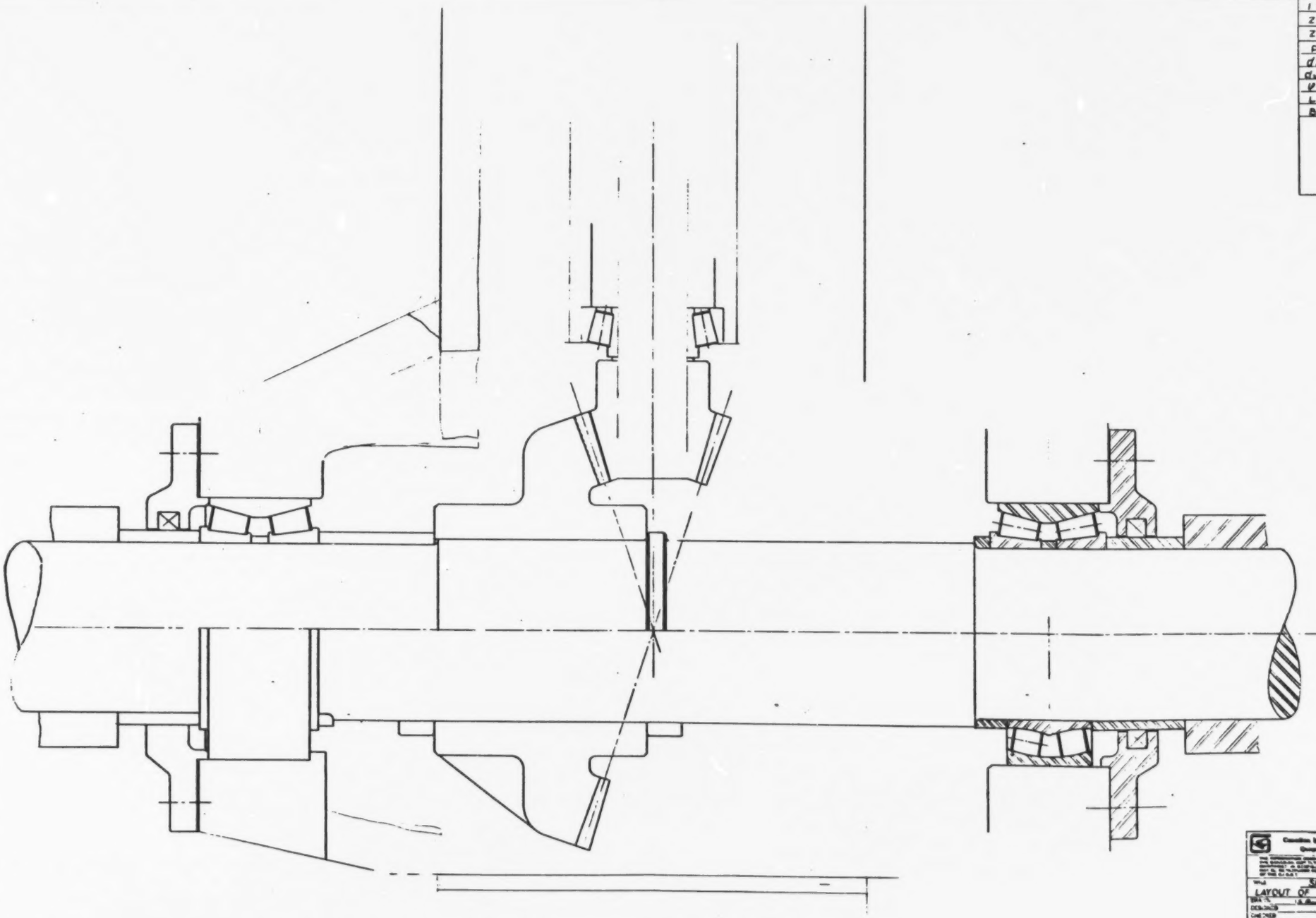
SNOWMASTER
GENERAL ASS'Y (SECTION)

JOB/CONTRACT NO.
265

DWG NO. 2P. REV 0

SCALE 1" = 1' SHT 5 OF 9 WEIGHT

I = 3.1	
Z_1 = 20	
Z_2 = 60	
P = 5	
α_1 = 9°	
α_2 = 12°	
V = 18.435°	
L = 6.325°	
B = 1.265	



Canadian Institute of Guided Ground Transport
Queen's University, Kingston, Ontario

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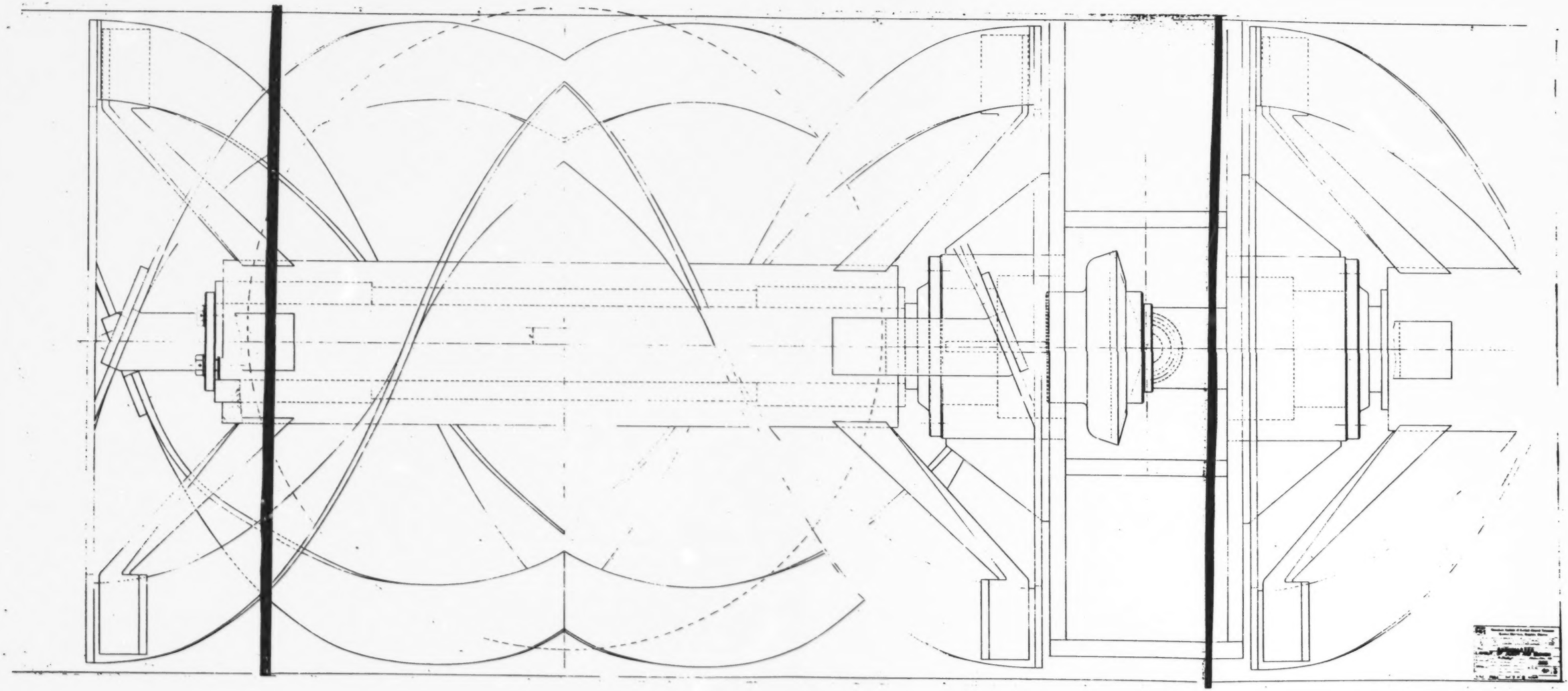
SNOWMASTER
LAYOUT OF GEARBOX ASS'Y

DRN. [illegible] — ASSIGNMENT NO.
DES. [illegible]
CHK'D [illegible] — 265
APPR'D [illegible] — DWG. NO. 3P10 — REV.

SCALE FULL — SHT. 1 OF 1 — SIZE A



APPENDIX F

PARTS LIST

Item	Description	Reference Information	Qty	Remarks
1	Snowblower Casing	Fabrication	1	
2	Snowblower Wings	Fabrication	2	
3	Blower Wing Cylinder	Assembly	2	Hydraulic
4	Coupler	AAR Standard E.	2	
5	Elevation Wedge	Fabrication	1	
6	Deploying Arm	Fabrication	2	
7	Snow Plough	Fabrication	1	
8	Bracket	Fabrication	2	
9	Deploying Arm Elbow Cylinder	Assembly	2	Hydraulic
10	Bracket	Fabrication	2	
11	Emergency Door	Assembly	1	
12	Rotating Arm	Fabrication	2	
13	Rotating Body	Assembly	1	
14	Entrance Door	Assembly	2	
15	Flat Car Wing	Fabrication	4	
16	Turntable Hydrostatic Motor with Pinion	Assembly	1	
17	Flat Car	Fabrication	1	
18	Main Wing	Fabrication	2	
19	Wing Cylinder	Assembly	4	Pneumatic
20	Wing Cylinder	Assembly	2	Pneumatic
21	Turntable Wedge Cylinder	Assembly	4	Hydraulic
22	Truck	Assembly	2	
23	Flanger Cylinder	Assembly	2	Hydraulic
24	Flanger	Assembly	1	
25	Auger	Fabrication	2	

Item	Description	Reference Information	Qty	Remarks
26	Pipelines			
27	Turntable Spur Gear	Steel	1	
28	Hydraulic Ram	Assembly	1	
29	Lifting Frame	Fabrication	1	
30	Rotating Manifold	Assembly	1	
31	Clear View Screen	Assembly	2	
32	Retractable Window	Assembly	2	
33	Traction Gear	Assembly	1	
34	Traction Motor	Assembly	1	Hydraulic or Electric
35	Locking Cylinder	Assembly	1	Hydraulic
36	Plough Pivot Column	Steel	1	
37	Bracket	Fabrication	2	
38	Removable Half Bearing	Steel	1	
39	Swinging Cylinder	Assembly	2	Hydraulic
40	Shaft	Steel	2	
41	Synchronizing Shaft	Assembly	1	
42	Top Deflector Plate	Steel	1	
43	Deflector Plate	Steel	2	
44	Horizontal Rib	Steel		
45	Vertical Rib	Steel		
46	Bottom Plate	Steel	1	
47	Rotary Activator	Model 1.5 HH 180° Rotation	2	Ohio Oscillator
48	Stairs	Fabrication		
49	Bulkhead Door	Fabrication	1	
50	Wedge Buffer Stop	Fabrication	1	
51	Fixed Half Bearing	Steel	1	
52	Lock Pin	Steel	1	

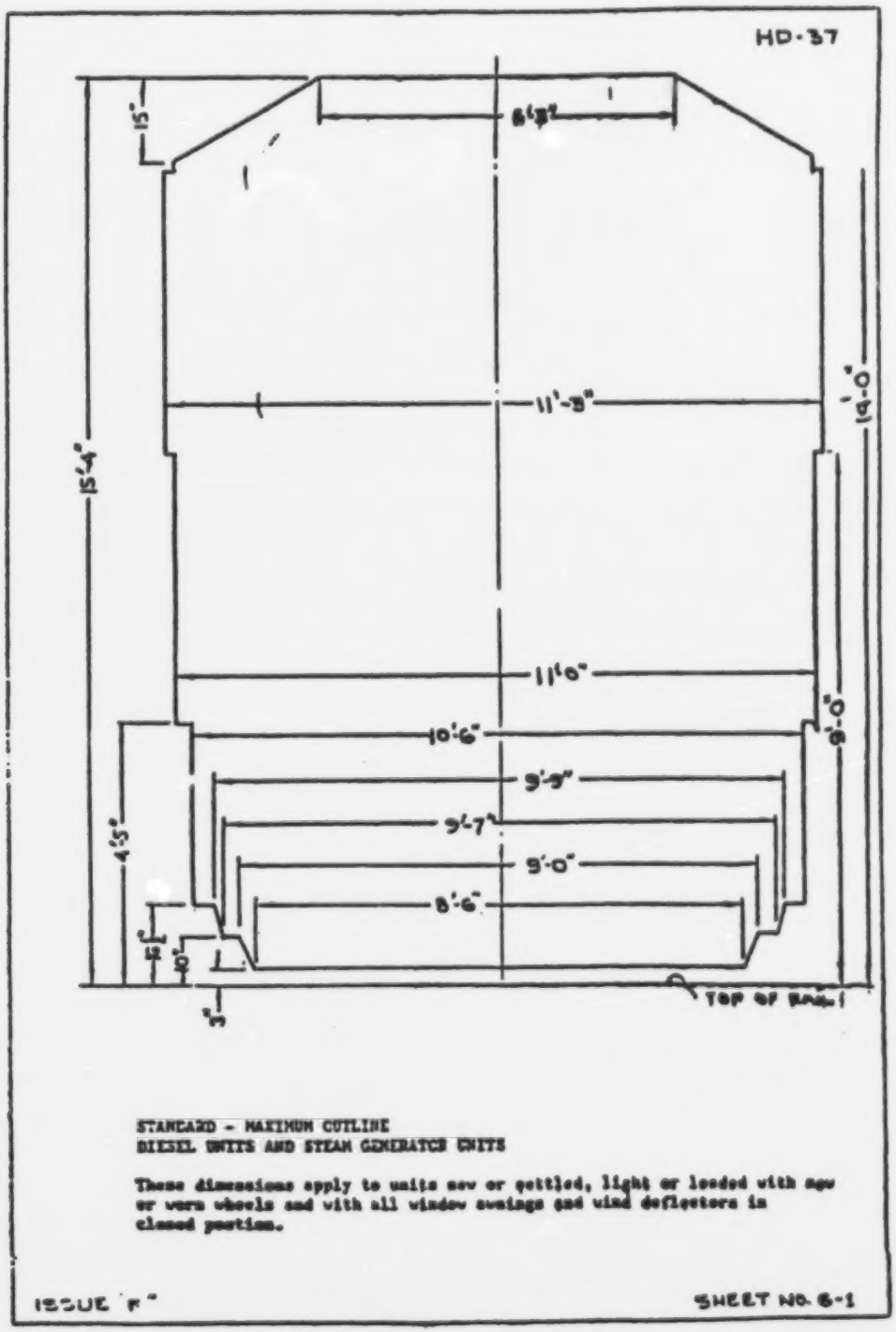
Item	Description	Reference Information	Qty	Remarks
53	Bracket	Fabrication	4	
54	Auger Drive Motor	Fixed displacement N°11	1	Abex
55	Casing Drive Chain	Assembly	2	
56	Impeller	Assembly	2	
57	Blower Casing	Assembly	2	
58	Blower Casing Drive Motor		2	
59	Blower Drive Motor	Fixed Capacity No. 11	2	Abex
60	Sprocket Set	Steel	2	3:1 Ratio
61	Clevis Pin	Steel	4	
62	Journal Lock Plate	Steel	2	
63	Impeller Shaft	Steel	2	
64	Roller Bearing	Single Row	2	SKF
65	Bearing Housing	Steel	2	
66	Bearing Cartrige	Steel	2	
67	Bearing Cap	Steel	2	
68	Tapered Roller Bearing	Tipe TDO	2	Timken
69	Locking Nut	Steel	1	
70	Snow Deflector	Fabrication	1	
71	Auger Shaft	Steel	1	
72	Gearbox Cover	Steel Plate	1	
73	Bevel Gear	Steel	1	
74	Bevel Pinion	Steel	1	
75	Tapered Roller Bearing	Single Row	2	Timken
76	Locking Nut	Steel	2	
77	Coupling	Steel	1	
78	Bearing Cartrige	Steel	1	
79	Blower Drive Cover	Steel Plate	1	

Item	Description	Reference Information	Qty	Remarks
80	Roller Chain Drive	Assembly	2	
81	Front Lights	Assembly	2	
82	Dash Board	Assembly	1	
83	Drivers Seat	Assembly	1	
84	Sliding Window	Glass	1	
85	Crew Seat	Assembly	1	
86	Guard Rail	Fabrication	1	
87	Front Sliding Window	Glass	1	
88	Wind Screen	Assembly	1	
89	Rear Window	Glass	1	

APPENDIX G

FIGURES

1. CN Spec. H.D.37, Sheet 6-1
2. CN Standard Clearance Diagram RIU.1.1 (March 1941)
3. Equipment Restriction Diagram
4. (a), (b) and (c) Movement of Snow Over Elevation Wedge Surface
5. Trajectories of Snow Leaving Elevation Wedge Surface (relative to vehicle)
6. Geometry of Movement of Snow over Elevation Wedge



STANDARD - MAXIMUM OUTLINE
DIESEL UNITS AND STEAM GENERATOR UNITS

These dimensions apply to units new or settled, light or loaded with new or worn wheels and with all window awnings and wind deflectors in closed position.

ISSUE "F"

SHEET NO. 6-1

Figure 1

SPC 2163

APPENDIX A

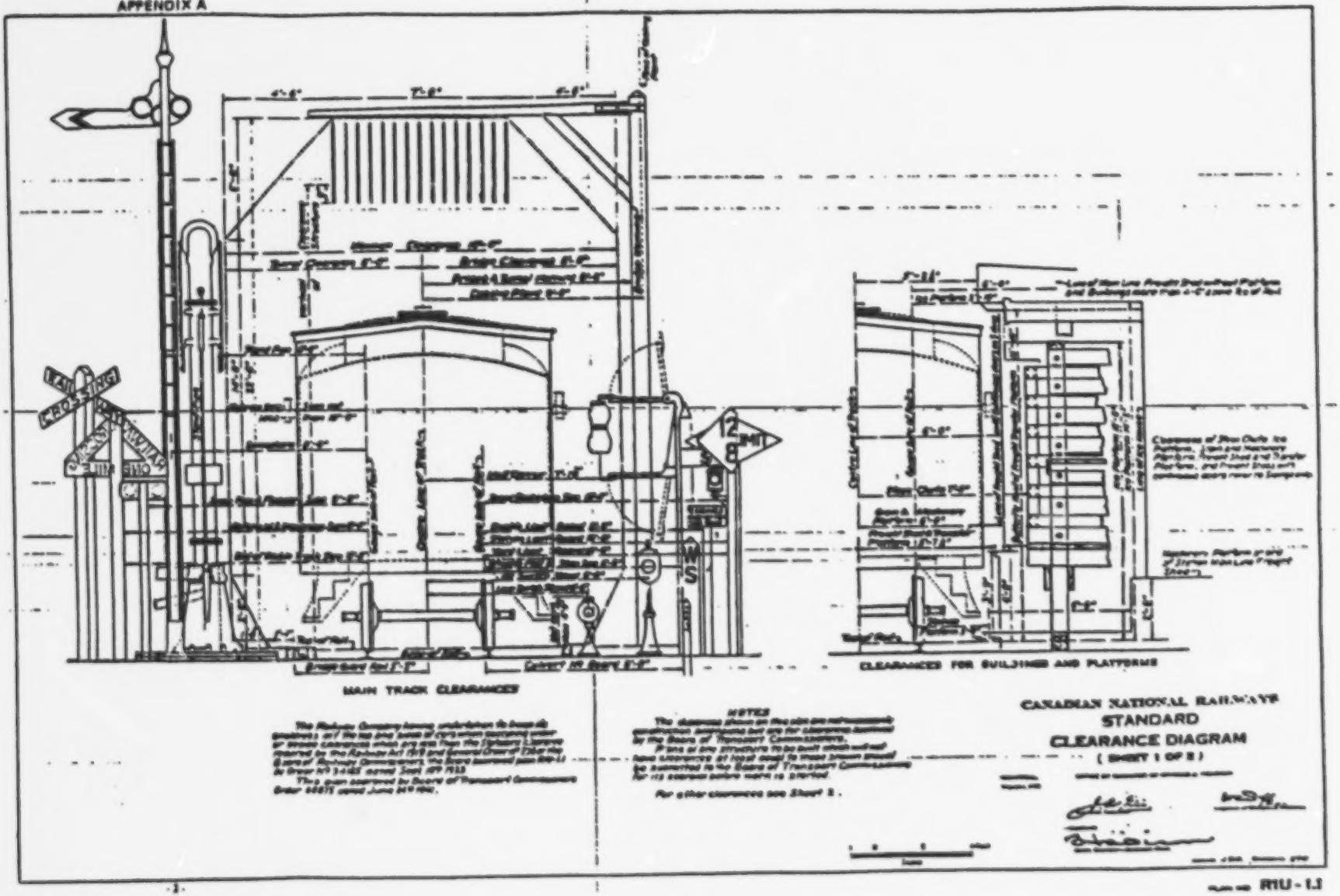


Figure 2

EQUIPMENT RESTRICTION

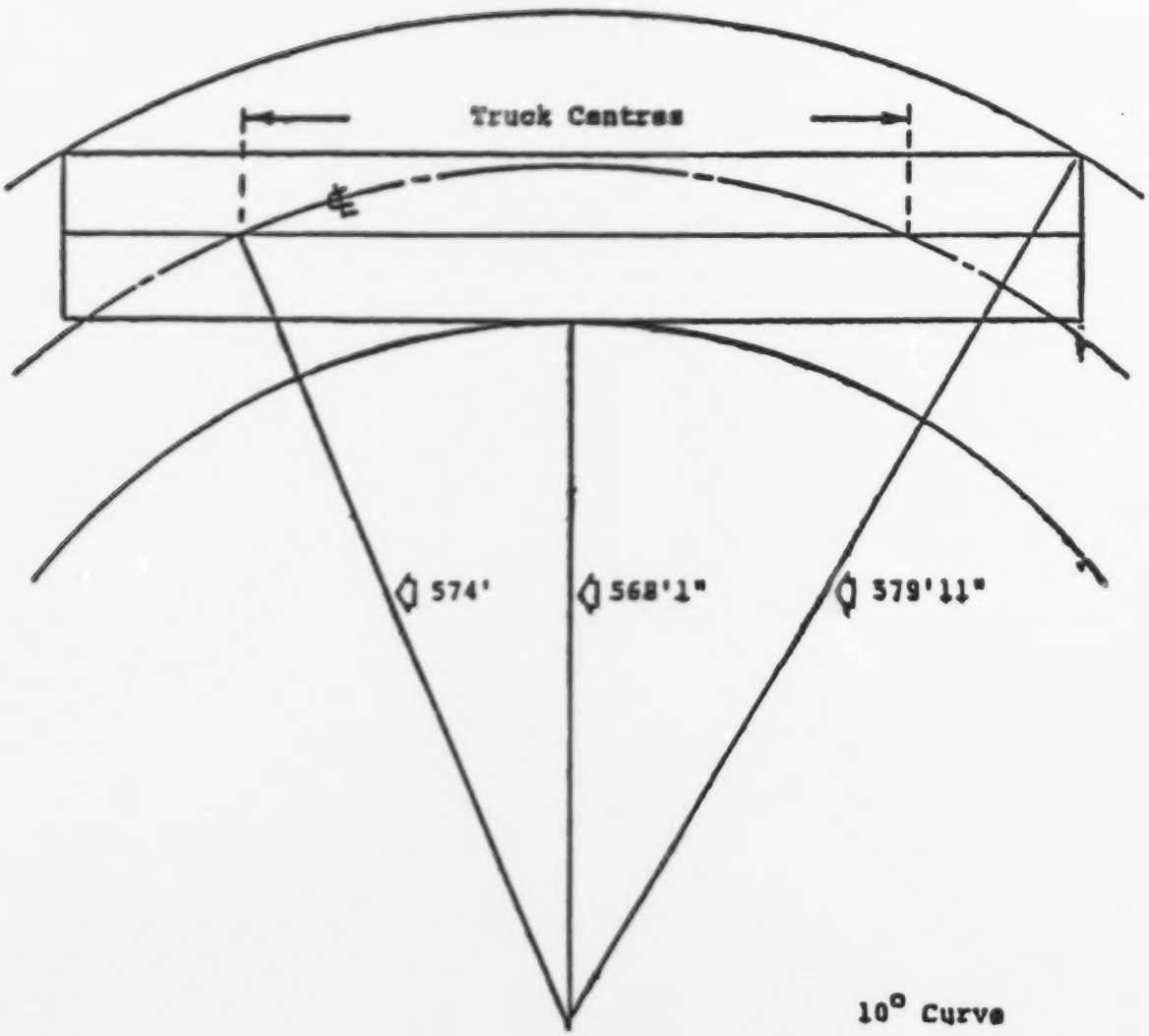
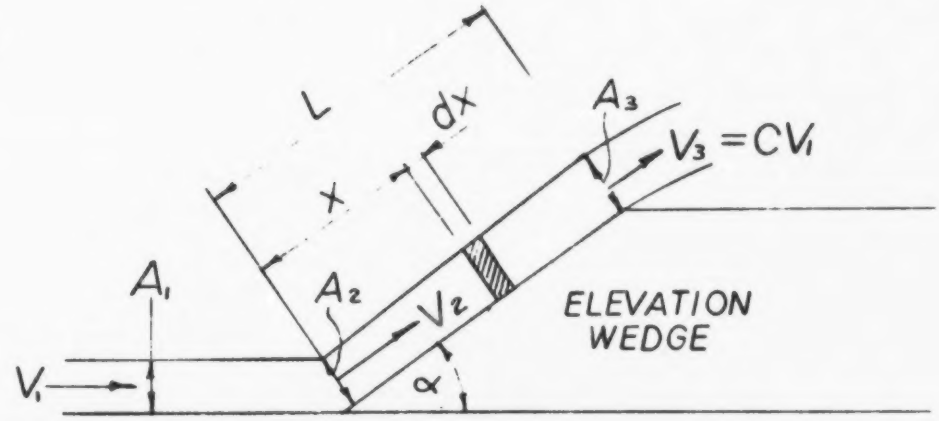
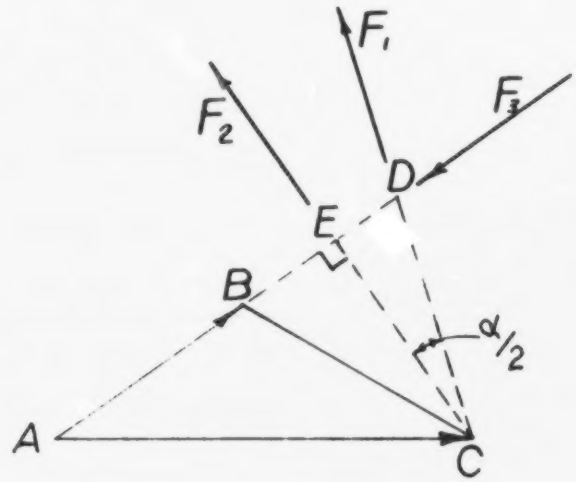


Figure 3

(A)

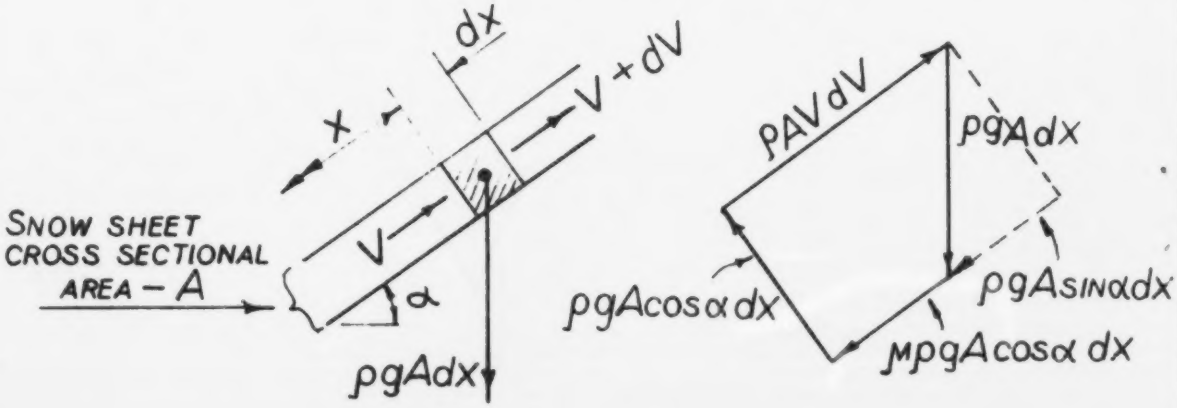


(B)



$\overrightarrow{AC} = V_1$ $\overrightarrow{AB} = V_2$

(C)



MOVEMENT OF SNOW OVER ELEVATION WEDGE

FIG. 4

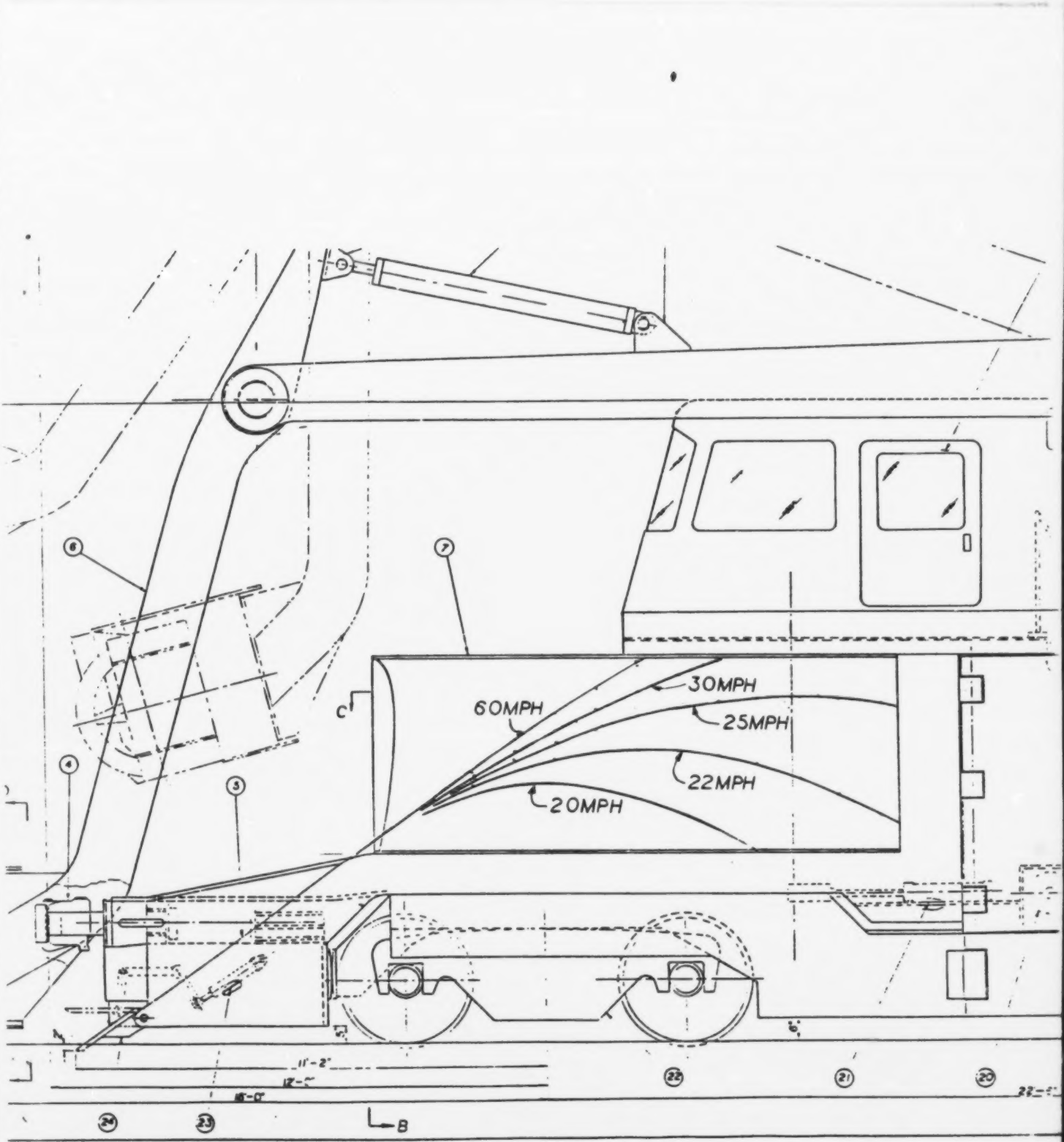
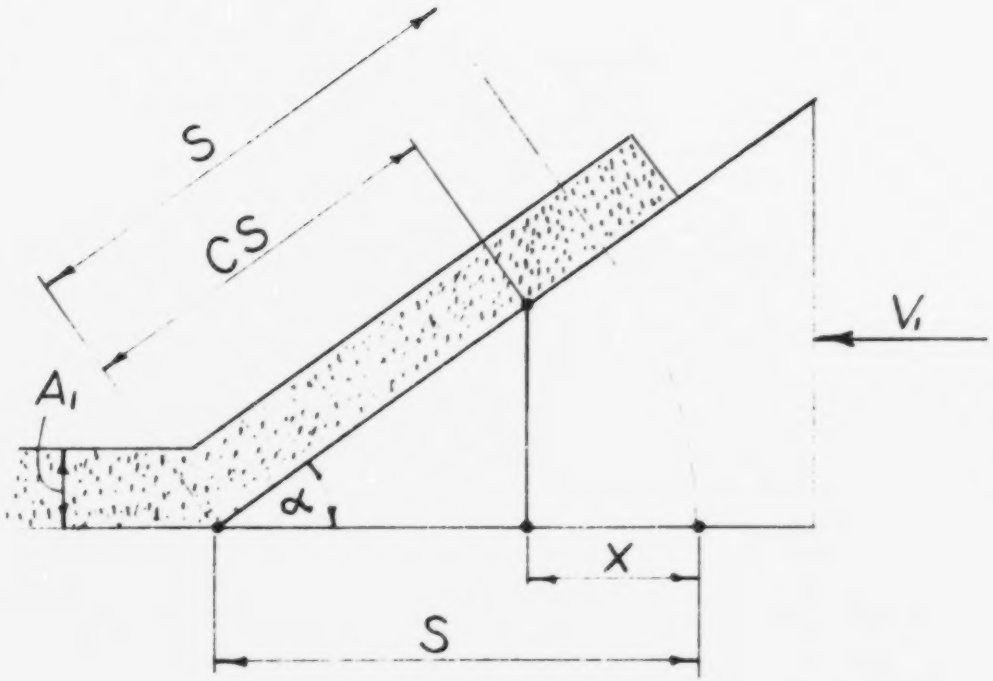


Figure 5 Trajectories of the Snow Sheet Leaving the Elevation Wedge Surface



GEOMETRY OF MOVEMENT OF SNOW OVER THE ELEVATION WEDGE

FIG. 6

APPENDIX H

REFERENCES

1. Snow Fighter Mark 1 -- Transportation Planning, Montreal. CN Rail Operations Report.

2. Railway Snow Removal Equipment, Phase 1, Transport Canada Report No. TP-2180.

3. "Snow Studies in Germany," Technical Memorandum No. 20 (M.G. Bekker), National Research Council of Canada, Assoc. Committee on Soil and Snow Mechanics.